Engineering Library

Technical Paper 294

DEPARTMENT OF THE INTERIOR

ALBERT B. FALL, SECRETARY

BUREAU OF MINES

H. FOSTER BAIN, DIRECTOR

REMOTE STORAGE

PROGRESS OF INVESTIGATIONS ON LIQUID-OXYGEN EXPLOSIVES

Engineering Library

BY

S. P. HOWELL, J. W. PAUL, and J. L. SHERRICK

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

Generated on 2024-09-29 23:29 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

Digitized by Google

Original from
UNIVERSITY OF ILLINOIS AT
URBANA-CHAMPAIGN

The Bureau of Mines, in carrying out one of the provisions of its organic act—to disseminate information concerning investigations made—prints a limited free edition of each of its publications. When this edition is exhausted, copies may be purchased at cost from the Superintendent of Documents, Government Printing Office, Washington, D. C.

The Superintendent of Documents *is not an official of the Bureau of Mines.* His is an entirely separate office and he should be addressed:

SUPERINTENDENT OF DOCUMENTS,
Government Printing Office,
Washington, D. C.

The general law under which publications are distributed prohibits the giving of more than one copy of a publication to one person. The price of this publication is 15 cents.

II

First edition February, 1923.

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from
UNIVERSITY OF ILLINOIS AT
URBANA-CHAMPAIGN

622
Un32t
no. 294-300

PREFACE.

Various notes, descriptions, and patents, dealing with the use of liquid oxygen as the oxidizing agent in explosive charges, had come from time to time to the attention of the Bureau of Mines, but the small production and high cost of liquid oxygen in the United States, as well as the cheapness of other explosive ingredients, made any study of such explosives seem inadvisable until the advent of the World War. Then our impending participation in that vast struggle and the consequent need for utilizing every facility for the conservation of materials for explosives, especially such materials as nitrates and other oxidizing substances, put the matter in a far different light, and demonstrated the advisability of undertaking a study of explosives that would utilize an oxidizing material obtained from the air by mechanical means. Furthermore, inquiries had come from various users of explosives as to the availability and practicability of liquid-oxygen explosives.

In consequence it seemed necessary that the Bureau of Mines should have first-hand information for the guidance of users of explosives in this country in the event of a shortage of other oxygen-carrying substances. Early in 1917, therefore, the Bureau of Mines decided to begin tests of liquid-oxygen explosives. This work was initiated by George S. Rice, the chief mining engineer, and conducted by the writers under his direction. The 1917 tests were made by Jacob L. Sherrick. The later tests were made by F. S. Crawford, H. L. Lentz, and Alan Leighton under the direction of J. W. Paul and are now being continued by V. C. Allison.

GEORGE S. RICE,
Chief Mining Engineer.

735854

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

CONTENTS.

	Page.
Introduction	1
Acknowledgment	4
Historical résumé	5
Liquefaction of gases	5
The so-called permanent gases	5
Industrial production of liquid air	6
Cooling by simple outflow compared with adiabatic expansion against a piston	6
The production of pure oxygen	7
Liquid-oxygen explosives	8
Properties of liquid air	9
Composition	9
Production of oxygen	11
Properties of liquid oxygen	12
Containers	12
Glass containers	13
Metallic containers	13
Materials used in explosives	15
Materials used in liquid-oxygen explosives	16
Oxidizing agents	16
Combustible materials	16
Absorbents	17
List of materials	17
Absorption and evaporation tests	17
Tests with 1-inch cartridges	17
Tests with 2¼-inch cartridges	19
Discussion of results	22
Explosive mixtures from evaporation tests	24
Comparison of various insulating materials and wrappers	24
Conditions of conducting evaporation tests	25
Tests with standard cartridges	26
Explosive mixtures for standard cartridges	27
Additional formulæ	27
Comparative tests of liquid-oxygen explosives	33
Trauzl lead-block tests	33
Conditions of test	33
Results of test	33
Discussion of results	35
Ballistic pendulum tests	35
Discussion of results	44
Detonation of unconfined cartridges	45
Discussion of results	45
Fuse and detonators for liquid-oxygen explosives	46
Summary	47

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Comparative tests of liquid-oxygen explosives—Continued. Page.
Rate of detonation tests 48
Discussion of results 48
Small lead-block test 49
Detonation of unconfined explosive probably not essential 49
Tests to determine suitability of liquid-oxygen explosives for use in gaseous and dusty coal mines 51
Flame test 51
Discussion of results 52
Products of combustion test 52
Gallery tests 53
Temperature calculations 53
Discussion of results 57
Miscellaneous tests 59
Analysis of liquid oxygen 59
Ballistic pendulum tests using No. 8 detonator 59
Detonation tests in cannon 59
Tests under water 59
Influence tests 60
Effect of moisture on the detonation of a wood-pulp cartridge 60
Comparative strength of wood pulp and sawdust at various times 60
Test of German detonator 60
Evaporation tests to determine the effect of decreasing the diameter of the cartridge upon the life of the cartridge 60
Evaporation tests to compare different kinds and thicknesses of wrappers 61
Effect of allowing cartridges containing paraffin to be more thoroughly mixed and hardened 61
Effect of subjecting dope to pressure before mixing into cartridges 62
Effect of liquid oxygen on detonators and fuse 63
Materials 63
Effect of liquid oxygen on detonators 63
Results 64
Effect of liquid oxygen on fuse 65
Conclusions 65
Field tests of liquid-oxygen explosives 65
Tests during 1917 65
Chambering shot at Morewood Extension, Pittsburgh, Pa 65
Block-hole and bench shots at No. 1 quarry of J. B. Ward & Sons, Pittsburgh, Pa 66
Tests during 1919, 1920, and 1921 68
Field test No. 1, No. 2 left butt, experimental mine, Bruceton, Pa 69
Field test No. 2, No. 1 left butt, experimental mine, Bruceton, Pa 70
Field test No. 3, No. 1 left butt, experimental mine, Bruceton, Pa 70
Field test No. 4, No. 6 room, experimental mine, Bruceton, Pa 71
Field test No. 5, No. 2 right butt, New England section, Pittsburgh Terminal R. R. & Coal Co., mine No. 7, Pittsburgh bed 71
Field test No. 6, No. 2 right butt, New England section 1, Pittsburgh Terminal R. R. & Coal Co., mine No. 7, Pittsburgh bed 72

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Field tests of liquid-oxygen explosives—Continued. Page.
Tests during 1919, 1920, and 1921—Continued.
Field test No. 7, face entry, New England section, Pittsburgh Terminal R. R. & Coal Co., mine No. 7, Pittsburgh bed 72
Field tests 8 to 15, block-hole shots in limestone 73
Field test No. 16, room 6, experimental mine 74
Field test No. 17, room 6, experimental mine 74
Field test No. 18, mine No. 7, New England section, Pittsburgh Terminal R. R. & Coal Co., Large, Pa 74
Field test No. 19, mine No. 7, New England section, Pittsburgh Terminal R. R. & Coal Co., Large, Pa 75
Field test No. 20, main haulage road, New England section, mine No. 7, Pittsburgh Terminal R. R. & Coal Co 76
Field test No. 21, main haulage road, New England section, mine No. 7, Pittsburgh Terminal R. R. & Coal Co 76
Field test No. 22, main haulage road, New England section, mine No. 7, Pittsburgh Terminal R. R. & Coal Co 77
Field test No. 23, Pittsburgh limestone quarry, Hillsville, Pa., bench shot, explosive 23A10 78
Dangers incident to use of liquid-oxygen explosives 78
Sensitiveness to flame 78
Impurities in explosive ingredients 79
Improper charging conditions 79
Action of low temperature on mercury fulminate composition 79
Selected bibliography on liquid air 81
Patents 84

TABLES.

TABLE 1. Equilibrium concentrations of liquid and gaseous oxygen-nitrogen mixtures 11
2. Absorption and evaporation tests with 1-inch cartridges, asbestos insulation 19
3. Absorption and evaporation tests with 2¼-inch cartridges, pasteboard insulation 22
4. Composition of dope of 25 liquid-oxygen explosives 23
5. Absorption and evaporation, standard cartridges 26
6. Absorbent mixture for standard cartridges 30
7. Fourteen Trauzl lead-block tests of liquid-oxygen explosives 34
8. Eight ballistic pendulum tests of liquid-oxygen explosives 36
9. Liquid-oxygen explosives 37
10. Seven detonations of unconfined cartridges 45
11. Three rates of detonation tests of liquid-oxygen explosives 48
12. Formulæ for liquid-oxygen explosives 50
13. Height and duration of flame of three explosives 52
14. Field tests 8 to 15, at mine No. 1, Pittsburgh Limestone Co., West Winfield, Pa 73

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

ILLUSTRATIONS.

		Page.
PLATE I.	Bureau of Mines dipping containers with felt-insulated carrying and supporting jacket	14
II.	The Simonis 20-liter metal container for liquid air or oxygen	15
III.	*A*, Parts of liquid-oxygen explosive cartridge; *B*, Enlargement of bore hole in Trauzl lead block produced by 10 grams of liquid-oxygen explosive	20
IV.	Steps in preparing liquid-oxygen cartridge	66
V.	*A*, Just before chambering shot of liquid-oxygen explosive; *B*, At moment of chambering shot, Morewood Extension, Pittsburgh, Pa	67
VI.	Test of liquid-oxygen explosives at Pittsburgh, Pa. *A*, Block before firing; *B*, Block at the moment of firing; *C*, Bench at the moment of firing	68
FIGURE 1.	Baly's curves, showing equilibrium concentrations of gaseous and liquid phase of nitrogen-oxygen mixtures at one atmosphere pressure	10
2.	Details of Bureau of Mines dipping container	14
3.	Evaporation curves for small (1-inch) cartridges	18
4.	Cross section of liquid-oxygen explosive cartridge	20
5.	Evaporation curves for 2¼-inch cartridges	21
6.	Comparison of weighing containers of standard cartridge, formula No. 13	25
7.	Evaporation curves for standard cartridges	26
8.	Calculation curves for oxygen for zero time	29
9.	Calculation curves for oxygen at end of 5 minutes	29
10.	Calculation curves for oxygen at end of 10 minutes	30
11.	Calculation curves for oxygen at end of 15 minutes	30
12.	Flames of permissible explosive, liquid-oxygen explosive, and black powder	51
13.	Effect of deficiency and excess of oxygen on the temperature of explosion of a liquid-oxygen explosive	57
14.	Conditions of field test No. 4, room 6, experimental mine	71
15.	Conditions of field test 7, mine No. 7, Pittsburgh Terminal R. R. & Coal Co	72
16.	Conditions of field test No. 8, mine No. 1, Pittsburgh Limestone Co., West Winfield, Pa	74
17.	Conditions of field test No. 20, mine No. 7, Pittsburgh Terminal R. R. & Coal Co	76
18.	Conditions of field test No. 22, mine No. 7, Pittsburgh Terminal R. R. & Coal Co	77

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

PROGRESS OF INVESTIGATIONS ON LIQUID-OXYGEN EXPLOSIVES.

S. P. Howell, J. W. Paul, and J. L. Sherrick.

INTRODUCTION.

Technical Paper 243 (31),[1] Bureau of Mines, by George S. Rice, covers the development of liquid-oxygen explosives in Europe during the war. In his conclusions regarding the use of these explosives, Mr. Rice said that the chief reasons for the slow progress prior to 1915, when the Germans started to use them, were as follows:

1. Use of liquid-oxygen explosives virtually requires the installation of a local liquid oxygen plant, involving a considerable first cost.

2. The explosive is not suitable for driving tunnels, sinking shafts, and extensive stoping, where a large number of shots must be fired at one time, because the charge must be fired within 10 or 15 minutes after the cartridge is dipped into the liquid oxygen. However, this disadvantage has been largely overcome by prearrangement of electric firing circuits.

3. A liquid-oxygen explosive can not be used in gaseous coal mines because it ignites fire damp.

4. Arranging practical methods of use in an ordinary mine or quarry is difficult because the miners or quarrymen have always been accustomed to using dynamite or black powder.

Mr. Rice summarized the advantages and disadvantages of using liquid oxygen as compared with dynamite and black blasting powder. The advantages were as follows:

1. Lower cost per unit of material blasted.

2. No danger in transporting explosives to point of use.

3. Practically no danger of premature ignition.

4. Elimination of the danger of misfires by a wait of 30 or 40 minutes after the fuse is lighted, when practically all the oxygen will have evaporated.

[1] Numbers in parentheses refer to similar numbers in the bibliography, p. 81.

Generated on 2024-09-29 23:29 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

5. Elimination of the danger of unexploded sticks in shoveling, and in subsequent handling of ore or coal going out of the mine.

6. No danger such as is experienced in handling and thawing frozen dynamite.

7. No danger from storage in magazines, as with dynamite and black powder, from lightning, fire, or other sources of ignition.

8. A liquid-oxygen installation is available for special purposes, such as supplying self-contained breathing apparatus or the oxy-acetylene torch.

The disadvantages were:

1. Because of rapid evaporation, liquid oxygen must be used quickly and within a definite time after the hole is charged, thus limiting the number of shots that can be fired in any one place to three or four, and making the firing of a group of shots, although possible, more difficult.

2. The practical necessity of having a liquefying plant near the mine to insure a supply.

3. To obtain liquid oxygen at low cost the plant must be kept running regularly; that is, it is not suitable for intermittent work.

4. Because of its igniting fire damp, liquid-oxygen explosive can not be used in gaseous coal mines.

In spite of the disadvantages, Mr. Rice believed that the explosive had great merit and might lessen blasting costs in certain classes of mining, as in (1) coal mines that at present use black powder or dynamite, are free from fire damp, and do not produce dust that is especially dangerous; (2) nongaseous anthracite mines; (3) iron, salt, and other mineral mines using a chamber method of mining where only a few shots are fired at one time; and (4) quarries where a few large shots could be fired at one time. The liquid oxygen could be placed in a special container, and because of the large quantity of liquid used in a single cartridge the evaporative loss would probably be small.

The chief item in the cost of liquid-oxygen explosive being the cost of the oxygen, there is hope of a decided reduction in cost through promised improvement in liquefying machines, as mentioned in Technical Paper 243.

The gradual increase in the cost of producing standard explosives and the resultant increase in the saving possible through the use of liquid-oxygen explosives will tend to overcome the natural opposition of miners and quarrymen who have always used other explosives.

Under the stress of necessity of providing nitrates for military explosives, the development in Germany, after the beginning of the war, was rapid. Liquid-oxygen explosive was

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

used in large quantities in the Upper Silesian coal mines, which were nongaseous, in tunnel work, in subway and excavation work in cities, in iron mining—not only in Germany, but also in the French iron mines of Lorraine which had been seized by Germany—and also for destroying French steel plants. French officials in the Briey iron district believed that the explosive introduced by the Germans had come to stay.

In Bureau of Mines Serial No. 2163 (32), of September, 1920, Mr. Rice further said that there were in operation 136 plants at coal, iron, potash, and salt mines throughout Germany, having a total capacity of 3,797 liters of liquid oxygen per hour. Allowing for losses, and calculating the time operated, a net total of 2,430,000 liters, or 5,346,000 pounds, of oxygen were used, equal to 8,000,000 pounds of dynamite.

One of the most interesting features of the development had been the design and construction of small portable liquid-oxygen-making plants of a capacity of only 3 to 5 liters of liquid oxygen per hour. Such plants have been constructed for moving about on trucks, thus making liquid oxygen much more available for small operators.

According to information received by Mr. Rice, a further important development in the use of liquid-oxygen explosives in Germany has been made through the prearrangement of a shot-firing circuit. Electric detonators are placed in receptacles set in a ball of clay and pushed to the back of each of the holes and are all connected so that, when ready to fire a round, the liquid-oxygen explosive cartridges are placed rapidly in the holes and covered with stemming, thus minimizing the time for preparing the round. It is claimed that as many as 28 shots have thus been fired in a round.

Under present conditions in this country introduction of the explosive will have to depend on demonstrated merits and advantages in comparison with explosives already in use.

Experiments on liquid oxygen as an explosive began at the Bureau of Mines testing station at Pittsburgh, Pa., in April, 1917. The results achieved up to July, 1921, may be summarized as follows:

1. A number of liquid-oxygen explosives have been made and investigated.

2. Absorption and evaporation tests were made on a number of absorbent and combustible materials.

3. It was found possible from the results of the absorption and evaporation tests to design explosive mixtures that would retain enough liquid oxygen after 15 minutes for the exact combustion of their combustible material to carbon dioxide and water. This allows a loading period of at least 15 minutes.

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

4. An efficient brass dipping container was designed to take the place of the fragile Dewar cylinder.

5. The Trauzl lead-block test was found rather unsatisfactory for determining the comparative strengths of liquid oxygen and nitroglycerin explosives, because of the smallness of the charge and the necessary variation in charging conditions.

6. The ballistic pendulum test was found suitable for comparative tests of liquid-oxygen explosives.

7. In the ballastic pendulum tests all of the liquid-oxygen explosives compared favorably with 40 per cent straight nitroglycerin dynamite, as regards strength.

8. A high percentage of oxygen in the liquid air is necessary for good results, and a 98 per cent liquid oxygen is recommended for such explosives.

9. Wood pulp as an ingredient of such liquid-oxygen explosives makes them less sensitive to detonation.

10. At least 20 per cent of crude oil, paraffin, or liquid hydrocarbon is necessary for detonation when unconfined. Diatomaceous earth is very efficient as an absorbent when these hydrocarbons are used.

11. Although certain of the mixtures do not detonate when unconfined, this is not of much importance, because in a short time the liquid oxygen evaporates and they cease to be explosive.

12. Preliminary tests seem to indicate that liquid-oxygen explosives are not suitable for use in gaseous and dusty coal mines.

13. Thermochemical calculations offer some hope of so modifying liquid-oxygen explosives as to make them suitable for use in coal mines by the addition of salts containing water of crystallization, such as sodium carbonate, and firing the explosives with a deficiency of oxygen. However, the inability to gauge exactly the amount of oxygen present in any case would make it seem inadvisable to use the explosives in gaseous and dusty mines, if their safe use depended upon firing with a deficiency of oxygen.

14. Although evaporation tests show that the life of liquid-oxygen cartridges increases with their diameter, 1¼-inch cartridges have been successfully used in certain of these investigations. It is evident, however, that the larger the diameter of cartridge used the more latitude there is as regards time of firing.

15. Electric detonators are the most certain means of firing a charge of liquid-oxygen explosive.

ACKNOWLEDGMENT.

The authors wish particularly to acknowledge their indebtedness to the English edition (1913) of the book by Georges Claude, "Liquid Air-Oxygen-Nitrogen."

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

HISTORICAL RÉSUMÉ.

LIQUEFACTION OF GASES.

The liquefaction of most of the gases then known was accomplished between 1792 (when Van Marum (25) first liquefied ammonia) and 1854. Such eminent scientists as Faraday, Collodon, Maugham, Anne, Berthelot, and Natterer contributed largely to this achievement. However, a number of gases, notably oxygen, nitrogen, hydrogen, methane, and carbon monoxide, resisted all efforts of these and other experimenters, and came to be known as "permanent gases."

The work of Andrews, in the period following the year 1863, served to throw light on the reasons for the peculiar behavior of these so-called permanent gases, and to emphasize the important rôle temperature played in liquefaction.

THE SO-CALLED PERMANENT GASES.

Not until 1877, however, was the liquefaction of these permanent gases accomplished. On December 2, 1877, Calletet, a French scientist, succeeded in liquefying both oxygen and carbon monoxide, and on December 22, 1877, Raoul Pictet, a Swiss, working independently and by a different method, liquefied oxygen. On December 24, 1877, Calletet, before the French Academy of Science, succeeded in liquefying methane, nitrogen, and air (25).

From Andrews's demonstration of the function of temperature in the liquefaction of gases it seemed certain that, if a low enough temperature were attained, any gas would liquefy even at atmospheric pressure. Pictet obtained the low temperatures necessary for the liquefaction of oxygen by what is known as the "cascade method," first evolved by Ch. Thellier (3). In this method progressively lower temperatures are obtained by causing liquefied gases, of progressively lower boiling points, to boil under reduced pressure. Thus each gas serves for the liquefaction of the next succeeding one until the gas in question has been liquefied. The cascade method was eagerly adopted by physicists, but it is necessarily complicated and would hardly admit of industrial application.

Calletet used a quite different method; he obtained the refrigerating effect by suddenly expanding a gas under pressure. This principle of the production of cold by expansion afterward proved to be the solution of the problem of producing liquid air and oxygen on an industrial scale. The expansion used by Calletet, however, was intermittent; in order to be applicable to an industrial process expansion must be effected continuously.

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

INDUSTRIAL PRODUCTION OF LIQUID AIR.

In order that a gas may cool itself by expansion it must do work against a resistance. Two methods of cooling were then known: 1, By virtue of work done against the attraction of the molecules themselves, that is, internal work as set forth in the experiments of Joule and Thompson; and, 2, by work done against an external resistance, such as a piston.

COOLING BY SIMPLE OUTFLOW COMPARED WITH ADIABATIC EXPANSION AGAINST A PISTON.

The cooling due to the Joule-Thompson effect has been expressed by the following equation:

$$d=0.276\ (p_1-p_2)\left[\frac{272}{T}\right]^2$$

where d=cooling, T=absolute temperature of expansion, and p_1 and p_2 are the pressures in atmospheres before and after expansion (25, 9).

The cooling caused by adiabatic expansion in a cylinder against a piston is given theoretically by the equation

$$\frac{T_0}{T_1}=\left[\frac{p_1}{p_2}\right]^{0.29}$$

where T_0=absolute temperature of compressed air, T_1=absolute temperature of expanded air, p_1=pressure in atmospheres of compressed air, and p_2=pressure in atmospheres of expanded air. Then T_0-T_1=cooling in degrees centigrade.

If these two equations are applied, it will be seen that with the first (Joule-Thompson) a fall from 40 atmospheres to one gives a cooling of 10° C., whereas adiabatic expansion gives a cooling of 175° C. (25).

A number of experimenters—among whom were Siemens, Solvay, Hampson, Thrup, and Linde—worked on the utilization of adiabatic expansion during the period 1857 to 1895, but all their efforts were fruitless; and Linde, drawing his conclusions from these fruitless efforts, expressed himself as believing that the difficulties were insurmountable (26). How these difficulties were overcome is related below.

The Joule-Thompson effect had been rather overlooked during the investigations, but in 1895 Hampson in England (7), Linde in Germany (8, 9), and shortly afterwards Tripler in the United States found in it the basic idea for the liquefaction of gases by simple outflow through an expansion valve. Without any discussion as to whom the right of priority belongs (27), it will suffice to record that their goal was reached only through the use of Siemens's

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

exchanger of temperature, with which the small initial cooling by simple outflow through an expansion valve could be used progressively to lower the temperature of the compressed gas.

Georges Claude, in France, not satisfied with the opinion of his predecessors as to the impracticability of using the expansion with external work for the production of cold, took up a study of this problem about 1899, and by using the properties of petroleum ether or high-grade gasoline to overcome lubrication difficulties was able in about 1902 to produce liquid air by the use of this method of cooling (4, 6). The efficiency of the method of liquefaction by external work, as advocated and perfected by Claude, was much greater, and resulted in yields of 0.95 liter of liquid air per horsepower hour, as compared with 0.50 in the Linde machines.

Probably most of the machines now in use for producing liquid air and liquid oxygen are of either the Linde or the Claude type, and to these two men may be assigned a large share of the credit for the industrial importance of liquid air to-day.

THE PRODUCTION OF PURE OXYGEN.

What after all was the industrial application of liquid air that the men who worked on the problem of liquefaction had in mind? There was some call for liquid air in scientific investigations for obtaining low temperatures, but certainly that demand would never necessitate any large industrial development.

Liquid air, or air in general, is a mixture of oxygen and nitrogen with a small percentage of other gases. The boiling point of liquid oxygen is −182.5° C., that of liquid nitrogen −195° C., and the mixture of the two gases in liquid air boils somewhere between these two temperatures. As the nitrogen has a lower boiling point than the oxygen, it would seem possible to separate the two gases in the mixture by fractional distillation and thus obtain pure nitrogen and pure oxygen. Indeed, Linde, in his original patent of 1895 (8), embodies an arrangement for the production of pure oxygen from liquid air. Most of the other patents taken out on the liquefaction of air contain arrangements for the separation of the oxygen and nitrogen, and this was the chief incentive that these men had for the production of liquid air on an industrial scale.

Up to 1900, however, this separation of liquid air into its constituents was based on the continuous evaporation of liquid air, which yielded at best only superoxygenated air and was very inefficient. The problem of obtaining pure oxygen was finally solved by the adoption of methods of rectification copied from those in use in the alcohol industries. In 1900 Georges Claude took out a patent, based on the rectification principle, for the separation of liquid air into

Generated on 2024-09-29 23:32 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

its constituents, but some of the ideas in the patent were faulty and impracticable (28). In 1902 Linde evolved the first workable apparatus for the rectification of liquid air (29). Later on other investigators in different countries took out patents employing this principle of rectification. In most of these patents the oxygen was taken out in the gaseous form and compressed into tanks, but it could also be taken out in the liquid form.

LIQUID-OXYGEN EXPLOSIVES.

Shortly after his successful solution of the problem of the production of liquid air in 1895, Linde conceived the idea of using liquid oxygen in combination with carbonaceous and other combustible materials for forming an explosive, and some of the blasting in the Simplon Tunnel (between Switzerland and Italy) was done in 1899 by the Gesellschaft für Linde Eismachinen with such an explosive (10).

Attempts have been made to use liquid air without any combustible material (30), by inserting in the drill holes metal cartridges that had been filled with liquid air and then closed. The high pressure from the gasification of the liquid air furnished the explosive force. These attempts evidently did not produce as good results as were expected, and, furthermore, there were numerous difficulties in application.

In 1906, in an article entitled "Oxyliquit," in the Zeitschrift für gesamte Schiess- und Sprengstoffwesen (10), Ludwig Sieder, of Munich, described two different methods of applying liquid air or oxygen to the absorbent combustible material of the cartridge. In one, the dipping method, the cartridges were immersed in the liquid until they were saturated, and then were quickly inserted in the drill hole. In the other method the cartridges, after they had been placed in the drill hole, were filled with liquid air or oxygen through small tubes. The latter method, that of preparing the explosive charges in the bore hole, was embodied in several patents by Baldus and Kowastch (11, 14). Otto Simonis in England proposed a cartridge of two compartments, one containing liquid air and the other the combustible material. The liquid air or oxygen in this cartridge was admitted to the combustible material either through the rupture of the partition by the pressure developed from the evaporating liquid, or, after tamping, by pulling a string attached to the partition (15). A number of patents (see bibliography) in different countries bear on explosives containing liquid oxygen. Some of these specify different methods of applying the liquid air or oxygen; others contain ideas as to the various means of forming and insulating the cartridges; and still others are on the applica-

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

tion of various combustible materials and absorbents. Of the combustible materials specified, charcoal, lampblack, crude oil absorbed in diatomaceous earth, aluminum powder, magnesium powder, calcium hydride, coal, and naphthalene may be mentioned. The absorbents other than combustible materials are diatomaceous earth or aluminum oxide.

PROPERTIES OF LIQUID AIR.

The critical constants for liquid air are a temperature of —140° C. and a pressure of 40 atmospheres. The maximum temperature at which air can exist in the liquid state is —140° C., and at this temperature it has a vapor pressure of 40 atmospheres. In common with all liquids, the vapor pressure of liquid air decreases with temperature, so that at about —190° C. liquid air has a vapor pressure of one atmosphere. This temperature is the boiling point of liquid air when exposed to atmospheric pressure. Most liquid-air machines, however, do not work with a pressure of one atmosphere in the liquefying chamber, but at higher pressures, namely, 40 to 50 atmospheres in Linde and 40 atmospheres in Claude machines; hence the liquid air in the machines has a temperature somewhere between —190° C. and the critical temperature —140° C. When this liquid is withdrawn from the machine, at about —155° C., into open vessels, it must have its temperature lowered to —190° C. in order to exist at the atmospheric pressure. This decrease is accomplished automatically through the latent heat of vaporization. When liquid air at a temperature of —155° C. and a pressure higher than one atmosphere is exposed to one atmosphere pressure a lively ebullition, or boiling, takes place, and as the heat necessary for vaporization is obtained from the liquid air itself, the temperature of the remaining liquid is lowered to about —190°C., which is the boiling point of the liquid air at atmospheric pressure.

If, then, liquid air, when taken from a higher pressure and temperature to the atmosphere, will automatically establish itself at about —190° C., it remains only to prevent the transfer of heat from surrounding objects to the liquid air in order to preserve the latter indefinitely. This, however, as will be seen in the following discussion on containers, is practically impossible, and the best we can do is to reduce the heat transfer as much as possible. As has been indicated, the best method of minimizing heat transfer is the use of vacuum-jacketed containers.

COMPOSITION.

Air is composed approximately of 21 parts of oxygen and 79 parts of nitrogen by volume or molecular parts; but liquid air, so

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

called, may have wide ranges of composition—a fact explainable by anyone who considers the relation of composition in the gaseous and liquid phases to temperature, as given by Baly's curves (23). Figure 1 shows the relation of the boiling points of the liquid to the composition of the liquid and gaseous phases at one atmosphere pressure.

Curve *a* represents the composition of the gaseous phase and curve *b* the composition of the liquid phase and boiling points of same. Thus, if we start with a liquid whose composition is repre-

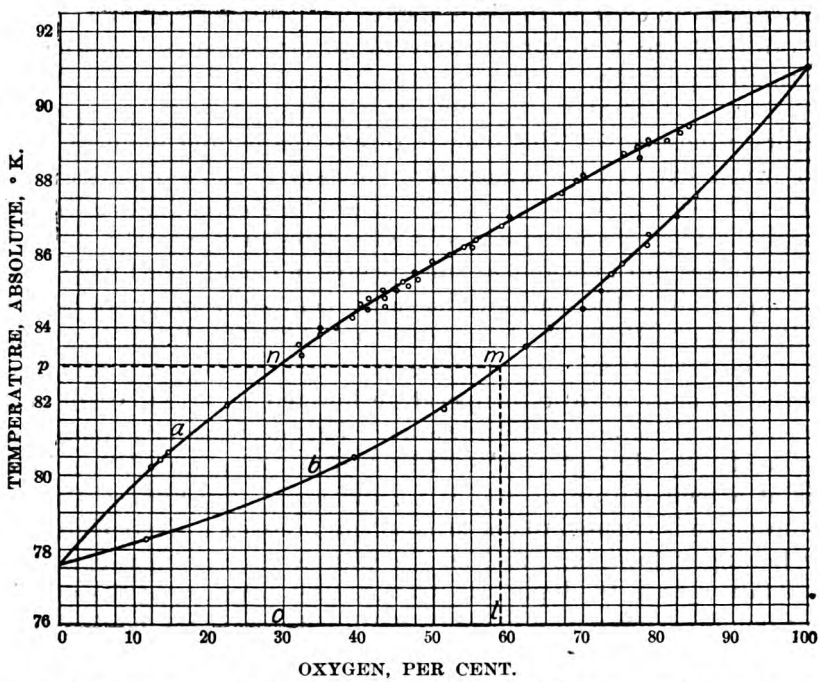


FIGURE 1.—Baly's curves showing equilibrium concentrations of gaseous and liquid phase of nitrogen-oxygen mixtures at one atmosphere pressure.

sented by *l*, about 59.55 mols per cent of oxygen, it will boil at about 83° absolute, as represented by *p*, and the composition of the vapor phase coming off will be 29.95 per cent oxygen, as represented by *o*.

The abscissas show molecular percentages of oxygen. Thus at point 20 the mixture contains 20 molecules of oxygen and 80 molecules of nitrogen, besides the small quantities of other gases, such as argon, etc. The temperatures are expressed in absolute degrees (°K.). Table 1 shows the composition of vapor and liquid phases for liquids of different boiling points at atmospheric pressure.

Generated on 2024-09-29 23:32 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

TABLE 1.—*Equilibrium concentrations of liquid and gaseous oxygen-nitrogen mixtures.*

Absolute temperature.	Per cent oxygen.		Absolute temperature.	Per cent oxygen.		Absolute temperature.	Per cent oxygen.		Absolute temperature.	Per cent oxygen.	
	Vapor phase.	Liquid phase.		Vapor phase.	Liquid phase.		Vapor phase.	Liquid phase.		Vapor phase.	Liquid phase.
[1] 77.54	0.00	0.00	81.00	17.66	43.38	84.50	40.45	69.31	88.00	69.58	87.60
78.00	2.18	8.10	81.50	21.22	47.92	85.00	44.25	72.27	88.50	74.37	89.82
78.50	4.38	15.25	82.00	23.60	52.17	85.50	48.17	75.10	89.00	79.45	91.98
79.00	6.80	21.60	82.50	26.73	55.94	86.00	52.19	77.80	89.50	84.55	94.09
79.50	9.33	27.67	83.00	29.95	59.55	86.50	56.30	80.44	90.00	89.80	96.15
80.00	12.00	33.35	83.50	33.35	62.93	87.00	60.53	82.95	90.50	95.10	98.16
80.50	14.78	38.53	84.00	36.86	66.20	87.50	64.85	85.31	[2] 90.96	100.00	100.00

[1] Boiling point of nitrogen; density 0.791.
[2] Boiling point of oxygen; density 1.131.

On examining the diagram, one sees that for a vapor phase containing 21 parts of oxygen there is in equilibrium with this a liquid phase containing about 47 parts of oxygen. Atmospheric air contains 21 parts of oxygen. Hence if evaporation could be eliminated entirely by preventing heat transfer, any liquid containing only liquid nitrogen and liquid oxygen in any proportions whatever would, if exposed to atmospheric air at a temperature of —190° C., come to equilibrium with this atmospheric air when there was about 47 per cent of oxygen in the liquid phase, even if we started from pure liquid oxygen or nitrogen. These equilibrium conditions are never reached, however, because heat transfer can not be prevented and the atmospheric air is not at —190° C.

PRODUCTION OF OXYGEN.

One of the first questions asked by anyone interested in the production of liquid oxygen from atmospheric air might be: Why is it not possible, by operation between the critical temperature of oxygen and the critical temperature of nitrogen, with the necessary pressure, to condense out the liquid oxygen in a pure state? Suppose that there were a pressure of one atmosphere in the liquefying chamber and a small quantity of pure liquid oxygen were obtained, this oxygen would not be in equilibrium with the gas above it in the chamber, and hence the liquid could not exist as pure oxygen but would soon reach the concentration of oxygen and nitrogen that would correspond with the gaseous phase above it. As a matter of fact, no pure liquid oxygen would condense, but the temperature must be lowered to a certain point, depending on the existing pressure, at which a liquid would condense in equilibrium with the gaseous phase above it.

The oxygen content of the so-called liquid air obtained from a liquid-air machine ranges about from 47 mols per cent to 21 mols

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

per cent. The higher figure would be realized when an infinitesimal part of the total air was liquefied, and the lower when all the air was liquefied; as a matter of fact, the oxygen content of the liquid obtained is usually about 33 mols per cent.

Figure 1 is important in considering the production of liquid oxygen from liquid air. The diagram shows that the vapor given off from the liquid mixture of oxygen and nitrogen is always richer in nitrogen and poorer in oxygen than the liquid remaining behind, so that by merely evaporating the liquid air a liquid is obtained progressively richer in oxygen. However, this process would be very wasteful for preparing liquid oxygen of any considerable degree of purity.

Only through the utilization of the rectifying principle is liquid oxygen of any great purity obtained. Liquid oxygen 98 per cent pure is now obtainable from the rectifying plants at a cost little, if any, higher than that of liquid air.

PROPERTIES OF LIQUID OXYGEN.

Liquid oxygen is a bluish liquid, with a density of 1.13; it is strongly magnetic, boils at —182.5° C., and freezes at —225° C.

If a glowing splint be placed above the surface of the liquid, the evaporating oxygen causes the splint to burst into flame, and if the splint be lowered into the liquid oxygen itself a lively combustion takes place below the surface of the liquid. If the size of the glowing splint is increased or a piece of glowing cork or charcoal is used the combustion is still livelier and some of the flaming fragments may be thrown out. From these lively actions under the surface of liquid oxygen it is not such a great step to extra rapid combustion or explosive reaction, which is the subject of this work.

CONTAINERS.

Because of the immense difficulties in the preservation of such a substance as liquid air, the development of containers for storage, transportation, and handling naturally became important. The necessity for preventing the transfer of heat from the surroundings to the liquid air was evident from the first, and was largely met, in apparatus for liquefaction and rectification, by insulation with dry sheep's wool. The best of the heat-insulating materials, such as sheep's wool, cork, and felt, are, however, inefficient for the preservation of liquid air. This is particularly true of receptacles for handling and other than stationary apparatus, where compactness is required, and the thickness of such insulating materials necessarily must be rather small.

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

GLASS CONTAINERS.

The first great step in the development of insulated containers for liquefied gases was the application by D'Arsonval of the heat-insulating properties of a vacuum. About 1887, D'Arsonval used double-walled glass receptacles, with a vacuum chamber between the walls; but even with these containers there still remained a disturbing source of heat transfer. Being transparent, these vessels permitted the transfer of radiant heat even across the vacuum chamber, and at best only reduced the evaporation to about one-tenth of what it would be in an unprotected vessel. The perfecting of these receptacles was due to Dewar, who by silvering the walls and thus retarding the transfer of radiant heat evolved the very efficient containers that are in use to-day.

However well, from the point of view of the scientist, these silvered-glass vacuum receptacles have solved the problem of preserving liquid air, nevertheless their extreme fragility would limit the application of liquid air to rather narrow fields, if dependence had to be placed upon them alone.

METALLIC CONTAINERS.

Some attempts have been made, especially for shipping liquid air, to use metal containers having the receptacle proper surrounded with a number of concentric chambers into which the cold vapors of the liquid air passed. In such containers not only would advantage be taken of the temperature differential set up, but the cold vapors could be used to counteract heat transfer. Several patents were taken out for containers of this type, but they evidently never realized expectations (17, 18).

It should be noted that the Dewar flask or container effectively reduces the transfer of heat, so that the evaporation of the liquid air in such a receptacle is only about one two-hundredth (1/200) of what it would be in an unprotected flask. A natural question is: Why not make these containers of metal instead of glass, and thus eliminate their great fragility, which is their sole drawback? There are two main reasons why metals are not as suitable; first, they conduct heat more readily than glass, hence would allow the ingress of more heat by conduction through the solid parts; second, all metals are more porous to gases than is glass, hence the vacuum obtained would not be as permanent. The increase of heat conductance is of slight import, because any heat entering by conduction must follow the metal walls around the vacuum chamber and proceed down the walls in a direction contrary to the current of the cold gases. Hence the heat of conduction would be largely transferred to the escaping

Generated on 2024-09-29 23:32 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

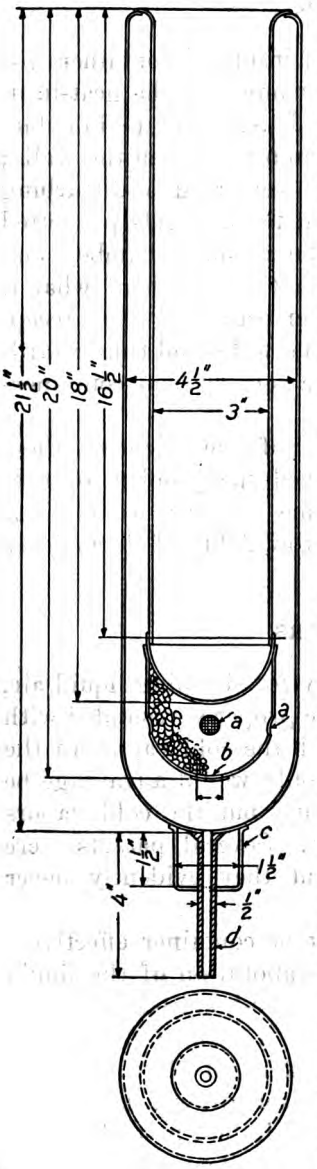
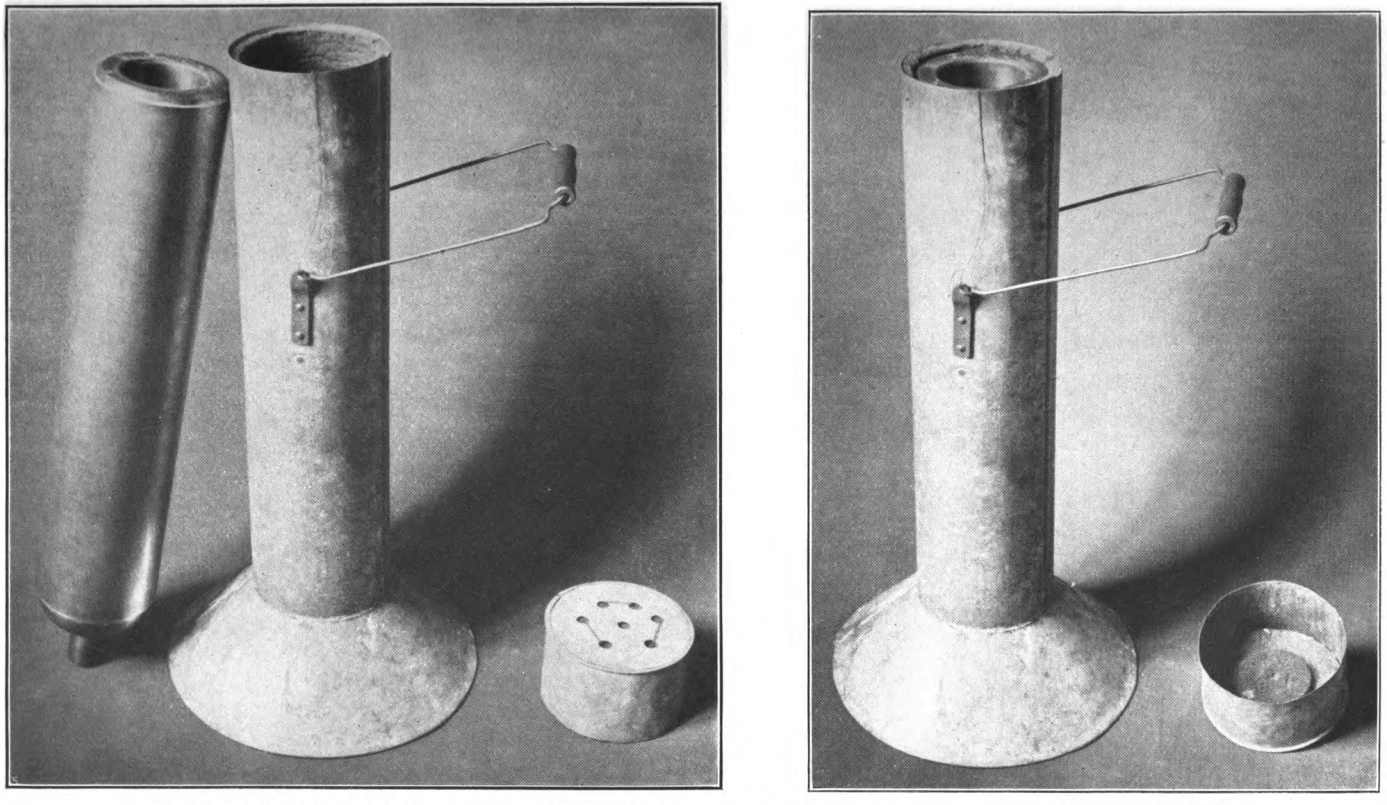


FIGURE 2.—Details of Bureau of Mines dipping container: *a*, 4¼ inch holes covered with 100-mesh brass screen; *b*, hole soldered tight after charcoal filling is in place; *c*, cap soldered in place after pipe is bent; *d*, lead pipe.

gases. The porosity of the metal, on the other hand, is of vital moment, as the slightest trace of gas in the space between the walls reduces the insulating effect enormously. Happily, through the work of Dewar (24), this porosity of metals can be made of rather small moment. Dewar found that wood charcoal absorbed enormous quantities of gases at the temperature of liquid air, and by its use almost perfect vacua could be obtained. In 1904 Dewar took out a patent for the production of high vacua by means of liquid air and charcoal, and under this patent metallic liquid-air containers have been made in England for a number of years (16). Doubtless such containers were also made for many years in Germany under this or other patents, as similar containers were found to have been used by the Germans in occupied territory. The accompanying illustration (Fig. 2) represents the mechanism of one of these containers, as made by the Bureau of Mines for dipping cartridges of explosive. It comprises a chamber to be evacuated, a false bottom containing wood charcoal and communicating with the vacuum chamber by small holes, covered with 100-mesh screen. The outlet to the vacuum chamber is a lead pipe, which may be sealed off when the vacuum is obtained and bent upon itself; a brass cap is soldered over it as an additional safeguard. Although the brass of which the vessel is made is slightly porous to gases, nevertheless when liquefied air is placed in the vessel the charcoal at this low temperature (−193.5° C.) quickly absorbs any gas that has gained access to the vacuum chamber, and automatically restores the insulating vacuum. Claude says that 15 grams of charcoal will absorb 250 c. c. of air at atmospheric pressure, with a tension lower than that of a Crookes's vacuum (25). With this data at hand, the proportion of charcoal to the capacity of the

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google



BUREAU OF MINES DIPPING CONTAINERS WITH FELT-INSULATED CARRYING AND SUPPORTING JACKET.

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

THE SIMONIS 20-LITER METAL CONTAINER FOR LIQUID AIR OR OXYGEN.

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

vacuum chamber can be made such that even with atmospheric pressure in the chamber initially, there will be, after cooling, the charcoal, an almost perfect vacuum, and the container will be effective almost indefinitely. Plate I, *A* and *B*, shows this dipping container with felt-insulated carrying and supporting jacket.

Dipping containers almost identical with this were used by the Germans in the Moyeuvre iron mine (31). The dipping container used by the Bureau of Mines was, however, designed independently by Howell and Sherrick.

When this investigation was started, the bureau had on hand two 20-liter brass spherical containers from which the essential features of the dipping container were taken. These spherical containers were bought some years before from Henry Simonis & Co., London, England. Plate II shows one of them as received from the manufacturer. During 1921 this container was opened in order to study its construction. The vacuum was perfect after 11 years of service.

Considerable difficulty was met in attempting to obtain a liquid-oxygen container and dipping vessel more efficient than those first used by Howell and Sherrick; but little success was obtained.

The Herold China & Pottery Co., of Golden, Colo., was not manufacturing any tubes or vessels of the necessary size. The Stanley Insulating Co., of New York, could not furnish a Stanley ferrostat vacuum bottle that was large enough. A gallon-capacity Aladdin thermalware jar was obtained from the Aladdin Industries Corporation, of New York, but the glass lining cracked as soon as liquid oxygen was poured in.

An insulating material called "silox" was obtained from the General Electric Co., and a dipping container was made by packing the silox around a glass tube, about 4 inches diameter, closed at one end and held in a wooden box. The level of the liquid oxygen poured into the tube fell one-half inch in 15 minutes, or 2 inches an hour, a rate that corresponds favorably with the rate of evaporation in the brass vacuum container, but the container devised is hardly to be considered much more efficient than the latter and did not eliminate the use of fragile glass.

MATERIALS USED IN EXPLOSIVES.

For a better understanding of the discussion that follows, it is desirable to classify the ingredients of commercial explosives on the basis of the chief function of each ingredient in the composite whole. Accordingly, the ingredients are classified as oxidizing agents, combustible materials, and absorbents.

Oxidizing agents supply the oxygen of the explosive; usually they are nitrates, chlorates, or perchlorates, although certain nitro bodies,

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

notably nitroglycerin, that contain more oxygen than is necessary for their own combustion may also be placed in this class.

Combustible materials supply the elements that unite with the oxygen in the explosive reaction; their component elements are usually carbon, hydrogen, and sulphur; they include a great variety of organic materials, such as wood pulp, flour, starch, nitrocellulose, nitrotoluene, nitroglycerin, etc.

Absorbents are of two kinds, inert and active. The more common absorbents used to hold the liquid ingredients of explosive mixtures are diatomaceous earth, wood pulp, and ammonium nitrate. The first is inert and functions only as an absorbent; wood pulp is an active absorbent and functions also as a combustible material; ammonium nitrate functions both as an absorbent and as an oxidizing agent.

This classification is far from perfect, for certain ingredients, such as the active absorbing materials, belong to more than one class. This is true of nitroglycerin also, which is both an oxidizing agent and a combustible material. The problem of selecting and proportioning suitable ingredients for liquid-oxygen explosives is, however, simplified by considering the classification.

MATERIALS USED IN LIQUID-OXYGEN EXPLOSIVES.

The choice of ingredients for liquid-oxygen explosives is narrower than for ordinary explosives, because the absorbent and the combustible material should be capable of absorbing such a quantity of liquid oxygen that at the moment of explosion, when a certain proportion has evaporated, there will still be enough oxygen for exact combustion of the combustible material. This is why the materials selected (see Table 2) have a high absorbing capacity. In any case, experiments are necessary to determine whether a given mixture is within the range of explosibility, whether this range is broad enough, and, if it is within that range, whether the propulsive and disruptive effects suffice for the purpose for which the explosive is intended.

OXIDIZING AGENTS.

The investigation of oxidizing agents was limited to liquid oxygen, although liquid oxygen may be contained in liquids that range from commercial liquid air containing 33 per cent oxygen to commercial liquid oxygen containing 98 per cent.

COMBUSTIBLE MATERIALS.

As the liquid oxygen must be retained by an absorbent, it is well that the absorbent be also a combustible material, in order to reduce

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

the amount of inert solid material present. It is important to note that wood pulp and lampblack meet this requirement much better than crude oil and paraffin.

ABSORBENTS.

All the mixtures that yielded good results contained diatomaceous earth; none of the others were worth consideration. Particularly in the use of crude oil and paraffin was this earth necessary, because they, as well as the liquid oxygen, required an absorbing material to hold them. In using paraffin it was melted and while melted was mixed with the earth.

LIST OF MATERIALS.

The following is a list of ingredients used by the authors and by others in experimentation:

Oxidizing agents.—Liquid oxygen in mixtures of oxygen and nitrogen ranging from 33 to 98 per cent oxygen.

Combustible materials.—Wood pulp, cotton, cheesecloth, lampblack, coal dust, wood charcoal, cork charcoal, paraffin, crude oil, and other liquid hydrocarbons, aluminum powder, magnesium powder, and sulphur.

Absorbents.—Diatomaceous earth and combustibles listed under combustible materials.

One notes particularly that nitroglycerin, nitrocellulose, nitrates, chlorates, perchlorates, and the aromatic nitro compounds are not in this list.

ABSORPTION AND EVAPORATION TESTS.

Liquid-oxygen explosives, because of the evaporation of the oxygen, continuously and rapidly change in composition, so that exact combustion conditions obtain only at a certain instant after the cartridge has been withdrawn from the dipping container. Hence it is of fundamental importance that the absorbing capacity of cartridges of the various absorbents and the rate of evaporation from them be determined. Having these data at hand, one may proportion the ingredients so as to obtain an explosive which will permit, between dipping and firing, a definite interval long enough to cover the time of charging holes.

TESTS WITH 1-INCH CARTRIDGES.

The first series of absorption and evaporation tests were made with cartridges of a size suitable for use in the Trauzl lead block. The need for insulation and the results obtained by other workers led to the use of two concentric cylinders closed at alternate ends and

Generated on 2024-09-29 23:32 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

fitting into each other. These cylinders were made of asbestos, were 25 mm. outside diameter, and differed in length to suit the particular cartridge. The cartridges themselves were made with cheesecloth wrappers to permit rapid absorption, and were 18 mm. in diameter. As the standard weight of charge used in the Trauzl lead-block test is 10 grams, these cartridges were made up so that when there was just enough liquid oxygen for exact combustion of the combustible material the cheesecloth cartridge plus the liquid oxygen would weigh 10 grams.

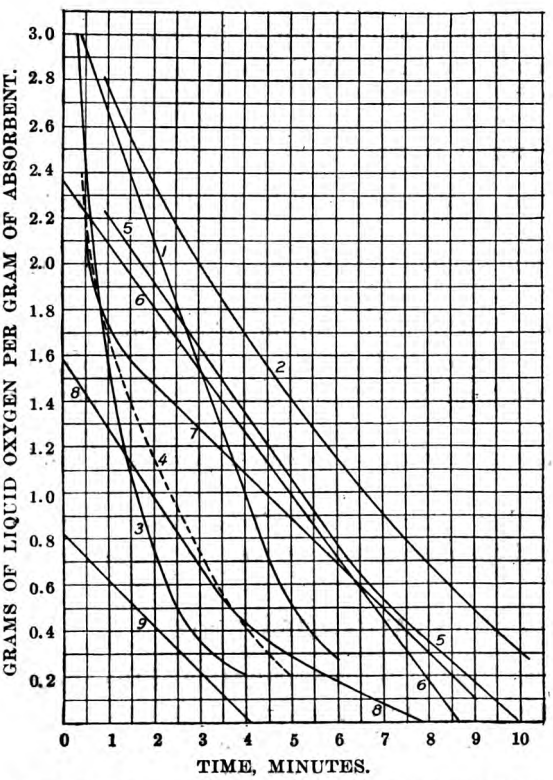


FIGURE 3.—Evaporation curves for small (1-inch) cartridges. For significance of curve numbers see Table 2.

In making the absorption and evaporation tests the cheesecloth cartridges were immersed in liquid oxygen and allowed to remain there for 10 minutes, which was long enough to saturate such small cartridges. The inner asbestos cylinder was slipped over the cheesecloth cartridge without removing it from the liquid oxygen. After this cylinder had attained the temperature of the bath—less than a minute sufficed—the cartridge was withdrawn from the liquid and the outer cylinder quickly fitted into place, completely covering it. The insulated cartridge was then placed on a scalepan and the amount of liquid oxygen present at intervals of one minute was determined. In this way the initial absorption and rate of evaporation of the liquid oxygen, under the given conditions of insulation, was determined. The figures obtained were for evaporation on the scalepan in free-moving air, and would not exactly represent but would be proportional to the evaporation in the bore hole of the lead block. The curves (Fig. 3) show the absorption capacities of the different materials, and the rate of evaporation therefrom under the given conditions of insulation and size of cartridge.

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Table 2 shows that wood pulp, cotton, cheesecloth, and mixtures Nos. 1 and 2 are the best with reference to oxygen absorption and evaporation, as all of these will retain sufficient oxygen for exact combustion for an appreciable length of time, the small diameter of cartridge and the very large area-volume ratio being considered. Of the other materials—lampblack, coal dust, and charcoal—the first has the best absorbing powers. All of these materials might be used, however, in mixtures containing diatomaceous earth, with the requirement satisfied that the mixtures have enough oxygen for exact combustion at a specified time.

TABLE 2.—*Absorption and evaporation tests with 1-inch cartridges, asbestos insulation.*

Absorbent material.	Liquid oxygen absorbed per gram of dope[1] (grams).	Liquid oxygen required for complete combustion of 1 gram of dope (grams).	Time till exact combustion conditions obtain (minutes).	Time till liquid oxygen completely evaporates (minutes).
1. Cotton	3.0	1.2	3.5	6.0
2. Diatomaceous earth	3.0	.....	.....	11.0
3. Loose roll of cheesecloth	2.8	1.2	1.5	4.0
4. Wood pulp	2.4	1.2	2.0	5.0
5. Lampblack	2.3	2.7	.....	10.0
6. 20 crude oil, 80 diatomaceous earth; mixture No. 2	2.3	.7	6.0	11.0
7. 40 crude oil, 60 diatomaceous earth; mixture No. 1	2.1	1.4	2.5	10.0
8. Willow charcoal, 200-mesh	1.6	2.7	.....	8.0
9. Bituminous coal dust, 200-mesh	.7	2.0	.....	4.0

[1] A term commonly used among explosives manufacturers to denote the absorbent material.

TESTS WITH 2 1/4 INCH CARTRIDGES.

In the second series of evaporation tests the cartridges used were $2\frac{1}{4}$ inches in diameter and were such as would be suitable for use in the ballistic-pendulum test. The cartridges were made up like the smaller ones, except that corrugated pasteboard was used in place of asbestos sheet for the insulating cylinders. The corrugated pasteboard, being combustible, was counted as an unmixed ingredient of the explosive, and allowance for sufficient oxygen for its combustion added to the quantity required for the cartridge proper. These cartridges were made up so that their weight, together with oxygen for exact combustion, would be 350 grams. The composition of a cartridge in which the dope was wood pulp is shown below:

Composition of cartridge containing wood pulp as dope.

Material.	Grams.	Per cent.
Wood pulp	92.5	26.4
Cheesecloth wrapper	6.0	1.7
Corrugated pasteboard insulators	60.5	17.3
Liquid oxygen	191.0	54.6
	350.0	100.0

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

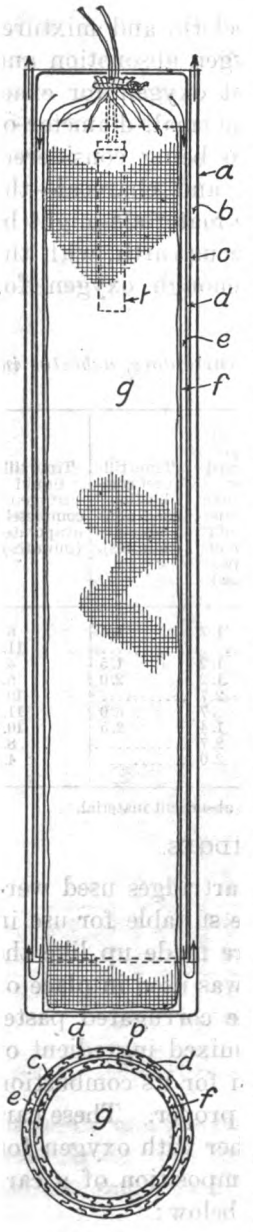


FIGURE 4.—Cross section of liquid-oxygen explosive cartridge.

One notes particularly the large percentage of liquid oxygen and the considerable quantity of corrugated pasteboard insulators used.

The inside cartridge, which had two thicknesses of cheesecloth wrapper, was 41 mm. in diameter, and slid freely into the inner pasteboard cylinder. The inner pasteboard cylinder was 50 mm. in outside diameter, and fitted freely into the outer cylinder, which was 55 mm. outside diameter. In every test a No. 6 electric detonator was placed in one end of the cheesecloth cartridge, and the cheesecloth was tied securely to the detonator legs, which passed through a small hole in the center of the closed end of the inner pasteboard cylinder. Plate III, *A*, shows the cartridge and insulators, and Figure 4 shows a cross section of the cartridge.

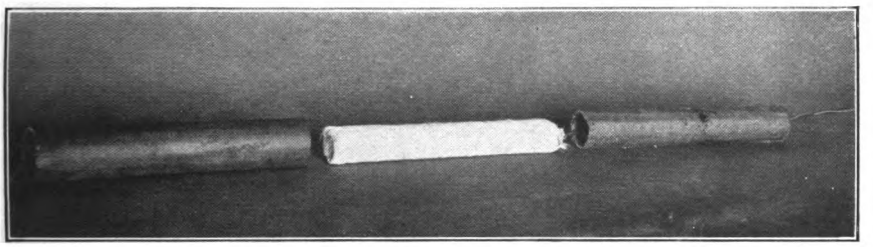
In Figure 4, *a* is the outside surface of the outer corrugated pasteboard insulator; *b* is the air space within the outer corrugated pasteboard insulator; *c* is the inner surface of the outer corrugated pasteboard insulator; *d* is the outer surface of the inner corrugated pasteboard insulator; *e* is the air space within the inner corrugated pasteboard insulator; *f* is the inner surface of the inner corrugated pasteboard insulator (it is in contact with the cheesecloth in the cartridge proper); *g* is the cheesecloth cartridge filled with dope and liquid oxygen; *h* is the electric detonator embedded centrally in one end of the cartridge.

The arrows show the path of the escaping oxygen gas.

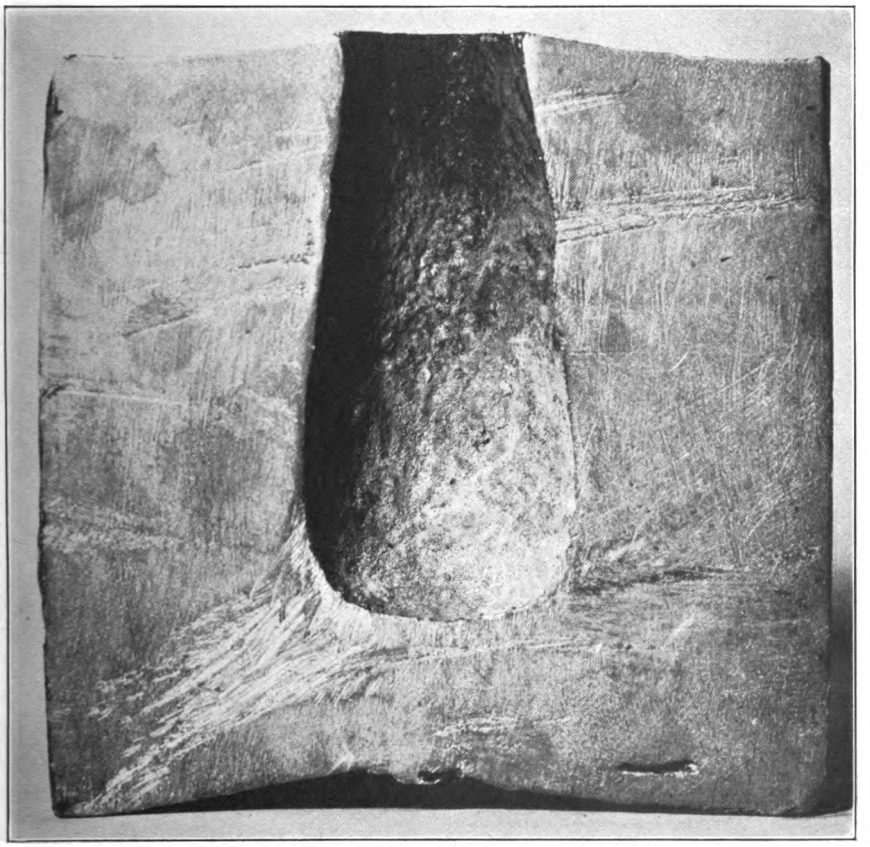
Attention is called particularly to the details of the insulated cartridge; the gaseous oxygen escapes only by a tortuous path, which retards the flow of heat from the outside to the inside of the cartridge.

The cheesecloth cartridge was immersed in liquid oxygen in a dipping container and allowed to remain for an arbitrary period of 20 minutes; then the inner cylinder, with the detonator legs protruding through the small hole in the closed end, was slid over the cheesecloth cartridge without removing it from the liquid oxygen.

Generated on 2024-09-29 23:30 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN



A. PARTS OF LIQUID-OXYGEN EXPLOSIVE CARTRIDGE.



B. ENLARGEMENT OF BORE HOLE IN TRAUZL LEAD BLOCK, PRODUCED BY 10 GRAMS OF LIQUID-OXYGEN EXPLOSIVE.

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

The cartridge was allowed to remain a few minutes in the liquid oxygen until the inner insulator was cooled to the temperature of the liquid oxygen, when the whole was withdrawn and thrust into the

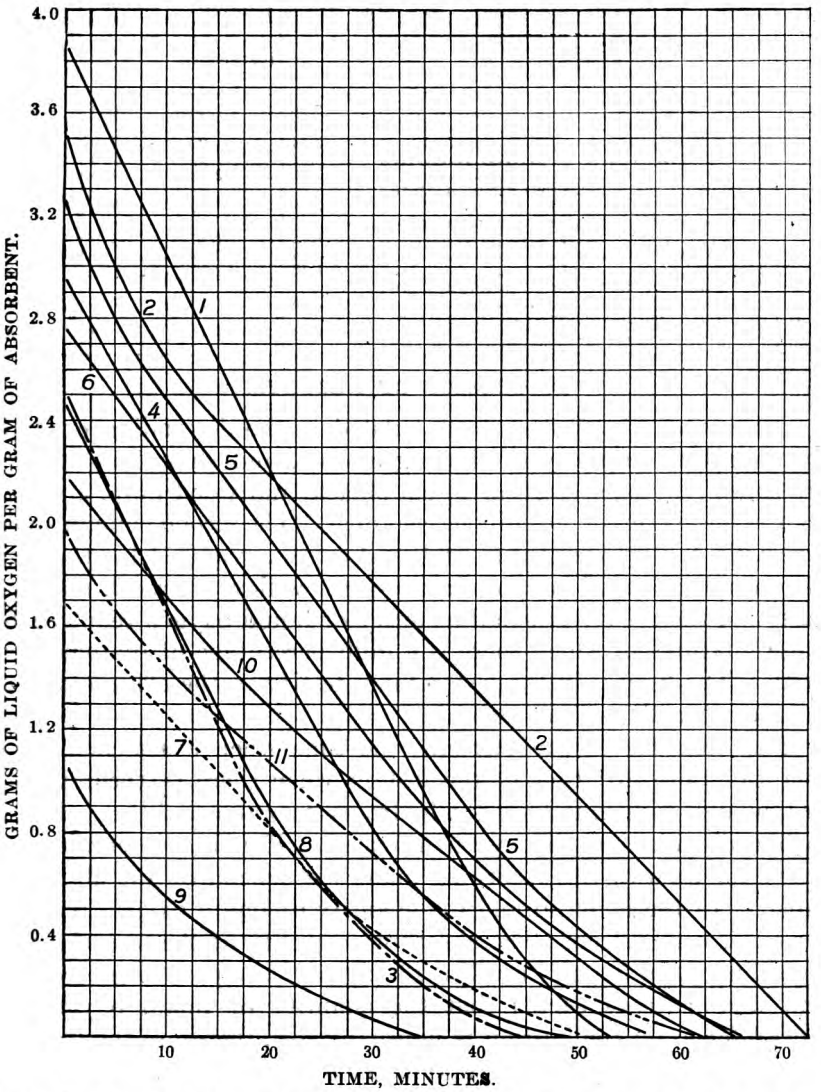


FIGURE 5.—Evaporation curves for 2¼ inch cartridges. For significance of curve numbers, see Table 3.

outer pasteboard cylinder. The insulated cartridge was then placed on the scalepan and the weight determined at intervals of one minute. Table 3 and the accompanying curves (Fig. 5) show the results of these tests.

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

TABLE 3.—*Absorption and evaporation tests with 2¼ inch cartridges, pasteboard insulation.*

Curve No.	Absorbent material.	Liquid air absorbed per gram of ingredient, grams.	Liquid oxygen required for complete combustion of 1 gram of ingredient, grams.	Time till exact combustion conditions obtain, minutes.	Time till liquid oxygen completely evaporates, minutes.
1	Cotton	3.90	1.20	32.5	53.0
2	Diatomaceous earth	3.54	.....	.....	73.0
3	Cheesecloth (tight roll)	2.54	1.20	16.0	47.0
4	Wood pulp	2.94	1.20	25.0	57.0
5	Lampblack	3.32	2.72	6.5	66.0
6	20 crude oil, 80 diatomaceous earth, mixture No. 2	2.78	.70	40.0	67.0
7	40 crude oil, 60 diatomaceous earth, mixture No. 1	1.72	1.40	7.0	51.0
8	200-mesh willow charcoal	2.54	2.72	.....	50.5
9	200-mesh bituminous coal dust	1.10	±2.00	.....	36.0
10	20 paraffin, 80 diatomaceous earth, mixture No. 13	2.20	.70	37.5	63.0
11	40 paraffin, 60 diatomaceous earth, mixture No. 12	1.96	1.40	11.0	62.0

DISCUSSION OF RESULTS.

The results (Table 3) were tabulated in the descending order of the absorbing capacity of the ingredients, and show how efficient are cotton, diatomaceous earth, lampblack, and wood pulp, and how poor is the 200-mesh bituminous coal dust. The second column shows especially the large quantity of liquid oxygen required for the complete combustion of lampblack, 200-mesh willow charcoal, and coal dust, and the relatively small quantity of liquid oxygen required for those mixtures in which there is a high percentage of diatomaceous earth. The figures in the last column testify to the efficacy of diatomaceous earth as an absorbent.

It is desirable to predetermine the time when exact combustion conditions prevail; that is, the instant when there is, theoretically, just enough oxygen to burn the hydrogen to water and the carbon to carbon dioxide, but no oxygen in excess. The time intervals computed for each of the absorbing materials depend on the absorbing capacity of the material and the quantity of liquid oxygen required for exact combustion. The absorbing capacity of the material may be ordinary, as for mixture No. 13 (20 per cent paraffin and 80 per cent diatomaceous earth), but the quantity of liquid oxygen required for exact combustion is unusually low, therefore the time interval of 37.5 minutes is exceptionally long. The table shows that 200-mesh willow charcoal and 200-mesh bituminous coal dust do not absorb enough liquid oxygen for exact combustion.

At first thought one might expect that cotton and wood pulp would make excellent ingredients, especially the latter because of its cheapness, but it is necessary to consider the facility with which detonation occurs, and the range within which it occurs, and the results of tests at the Pittsburgh experiment station with these two ingredients were not very promising.

Generated on 2024-09-29 23:32 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

TABLE 4.—*Composition of dope of 25 liquid-oxygen explosives.*

Mixture No.	Material of mixtures.												App. specific gravity of explosive, including liquid oxygen and corrugated paste-board insulator.	Time during which complete combustion will occur of a 2½-in. cartridge with corrugated paste-board insulator, from dipping container to firing shot, minutes.
	Crude oil.	Diatomaceous earth.	Lamp-black.	Wood pulp B.	200-mesh coal dust.	200-mesh charcoal.	Cotton.	Paraffin.	$MgSO_4$ $7\ H_2O$.	$Al(SO_4)_3$ $18\ H_2O$.	NaCl.	Diatomaceous earth saturated with water.	App. specific gravity of mixture.	
1	40.0	60.0											0.465	0.820	0 to ½
2	20.0	80.0											.300	.500	20
3	11.8	63.4	24.8										.444	.754	20
4	10.6	57.0		32.4									.382	.604	20
5	20.2	79.8													20
6	25.0	75.0													15
7	14.5	77.7			7.8										20
8	14.4	77.7				7.9									20
9	20.0	65.0		15.0									.405	.635	15
10	22.5	73.5	4.5												15
11	12.9	19.5					67.6								15
12		60.0						40.0					.465	.820	0 to ½
13		80.0						20.0					.300	.500	20
14		65.0		15.0				20.0					.405	.635	15
15		35.7		8.3				11.0	45.0						
16		56.0		12.9				17.3		13.8					
17		49.5		11.4				15.2		23.9					
18		35.7		8.3				11.0			45.0				
19		52.2						34.8			13.0				
20		51.0		15.0				34.0							0
21	10.0	60.0			30.0										0
22							100.0						.230	.487	19
23				100.0									.306	.552	12
24		100.0											.235		
25												100.0			

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

EXPLOSIVE MIXTURES FROM EVAPORATION TESTS.

From the results of evaporation tests on 2¼ inch cartridges, 25 explosive mixtures were prepared, as given in Table 4. Throughout the remainder of this paper the numbers given in the table are used to designate the mixture.

COMPARISON OF VARIOUS INSULATING MATERIALS AND WRAPPERS.

In the evaporation tests, data for which are given in Table 3 and Figure 5, concentric corrugated-pasteboard insulators were used. The idea of such insulation was taken from various articles in German magazines on liquid-oxygen explosives. These insulators were very efficient and the preliminary work had been done under the pressure of war-time conditions; an attempt was made to push the work to a point where enough information of a general nature would be available in order that liquid-oxygen explosives might be used in this country to conserve materials required for military explosives. In his investigations of the use of liquid-oxygen explosives by the Germans, Rice [1a] found that there was in use a much simpler insulating wrapper which consisted of two or three thicknesses of a very porous wrapping paper. Tests were therefore run to determine the relative insulating efficiency, as shown by evaporation losses, of the corrugated-pasteboard containers, shown in Plate III, *A*, and Figure 4 (p. 20) as compared with simpler cartridges made up with porous paper toweling.

The cartridges were made by using a whole towel (size 10¾ by 13¼ inches), rolling it the long way around a 1½-inch diameter glass tube, folding one end (about a 2-inch length) over the end of the glass tube, fastening with two rubber bands, and then removing the glass tube. These wrappers held their shape nicely, and the composition was pressed into them by using a metal or glass rod of sufficient diameter. When filled to within about 1 inch of the top, the wrapper was crumpled together and then held by means of a twisted rubber band.

A comparison of evaporation losses showed the corrugated pasteboard to be much the better insulator. As previously mentioned, however, the corrugated pasteboard because of its being combustible must be counted as an unmixed ingredient of the charge and enough oxygen allowed for its exact combustion in calculating the life of the cartridge. As the weight of the combustible pasteboard container was about two and one-half times that of the toweling for

[1a] Rice, G. S., Development of liquid-oxygen explosives during the war: Technical Paper 243, Bureau of Mines, 1920, p. 32.

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

the same size of cartridge, it was found that in spite of the greater evaporation losses the life of the simpler towel cartridge was much longer.

In an attempt to improve the wrappers still further other materials, as kraft, manila, newsprint, and bond papers, blotting paper, and asbestos, were tested but the paper toweling proved best. It was therefore adopted as standard and used in later tests.

CONDITIONS OF CONDUCTING EVAPORATION TESTS.

After the adoption of a new style of cartridge, it was necessary to obtain rates of evaportation for the different mixtures made up in such cartridges. The data on these rates as given heretofore had been obtained by weighing the cartridges on the scalepan in the freely circulating air of the room. In order that the conditions of the evaporation test should more nearly simulate charging conditions, the standard (paper toweling) cartridges were put in various containers before being placed on the scalepan and the net gain or loss of weight per unit weight of cartridge material was determined.

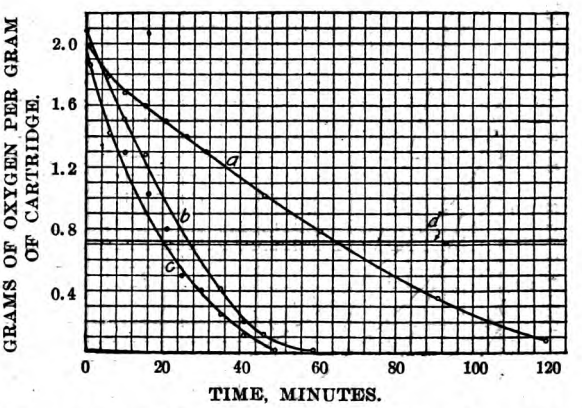


FIGURE 6.—Comparison of weighing containers of standard cartridge, formula No. 13: *a*, in cork, 66 minutes; *b*, in pasteboard, 28 minutes; *c*, in coal, 21 minutes; *d*, exact combustion.

The conditions of test were as follows:

(*a*) In a covered cork container with a 2-inch wall.

(*b*) In a bore hole in coal, for comparison with rate of evaporation in other containers.

(*c*) In an open pasteboard coal-sample carton.

Figure 6, which gives the results of these tests, shows that the rate of evaporation in the cork containers was much slower, but in the open pasteboard carton was practically the same as in the bore hole in coal. Further tests with other mixtures substantiated these findings and the open pasteboard carton was therefore chosen as standard in evaporation tests.

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

TESTS WITH STANDARD CARTRIDGES.

Using the standard (paper towel, 1½ inch) cartridge and placing the dipped cartridge in a pasteboard carton on the scalepan, further evaporation tests were made with various mixtures.

The results of these tests are given in Figure 7 and in Table 5 below.

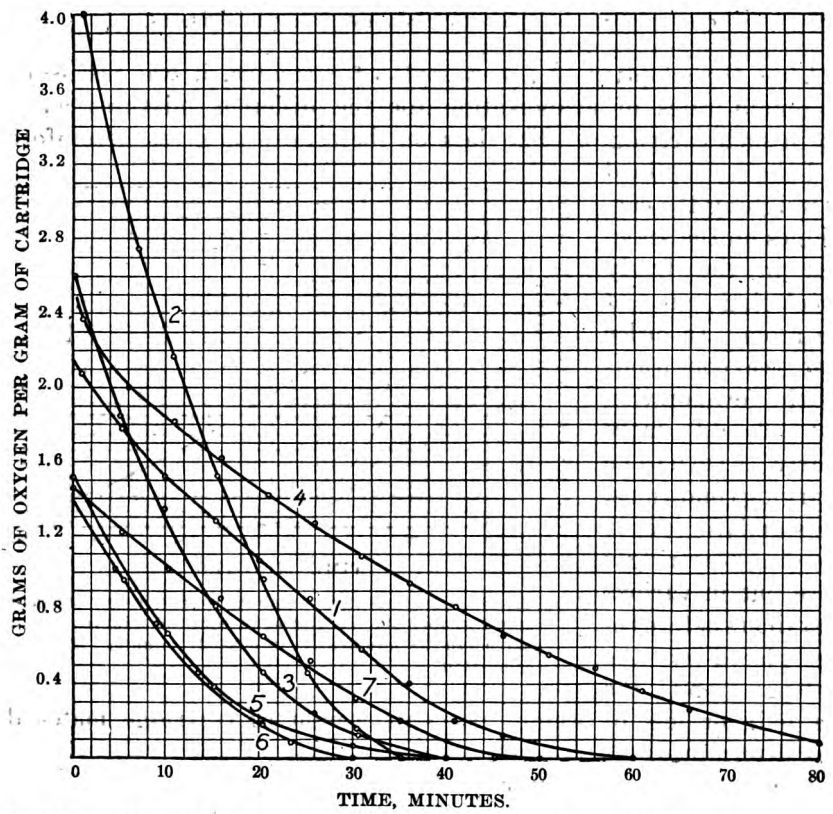


FIGURE 7.—Evaporation curves for standard cartridges. For significance of curve numbers, see Table 5.

TABLE 5.—*Absorption and evaporation, standard cartridges.*

Curve No.	Absorbent material.	Liquid oxygen absorbed per gram of cartridge (grams).	Liquid oxygen required for exact combustion of 1 gram (grams).	Time until exact combustion conditions obtain (minutes).	Time until liquid oxygen completely evaporates (minutes).
1	20 paraffin, 80 diatomaceous earth	2.10	0.70	28.0	60.0
2	Cotton	4.70	1.19	18.0	35.0
3	Wood pulp	2.60	1.37	10.0	45.0
4	Diatomaceous earth	2.40			91.0
5	25 paraffin, 75 wood pulp	1.51	1.89	Never.	35.0
6	25 naphthalene, 75 wood pulp	1.47	1.78	Never.	30.0
7	50 naphthalene, 50 diatomaceous earth	1.46	1.50	Never.	50.0

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

EXPLOSIVE MIXTURES FOR STANDARD CARTRIDGES.

The twenty-five formulae given in Table 4 were tested and most of them rejected for the reasons given in the table below.

Reasons for discarding formulae.

Formula No.	Reasons.
1	Useless for storage because of evaporation of crude oil; also, the time during which complete combustion will occur is not long enough.
2 to 11	Useless for storage because of evaporation of crude oil. In No. 11 there was difficulty in mixing ingredients.
12	Not enough time during which complete combustion will occur.
13 and 14	These formulae were accepted, but later in the investigation were recalculated for 5, 10, and 15 minute periods of complete combustion.
15	(Formula for permissibility test.) Hydrated sodium carbonate (10 H_2O) is better than magnesium sulphate (7 H_2O) because it is cheaper, but more especially because the cooling power per gram and not the cooling power per gram-mole should be considered for efficiency in lowering the temperature of the flame.
16 and 17	(Formulae for permissibility test.) Hydrated sodium carbonate (10 H_2O) is better than aluminum sulphate (18 H_2O) for reasons given above.
18 and 19	(Formulae for permissibility test.) Hydrated sodium carbonate (10 H_2O) is better than sodium chloride for reasons given above.
20	Time during which complete combustion will occur not long enough.
21	Useless for storage because of evaporation of crude oil; time during which complete combustion will occur is not long enough.
22	Too much waste of liquid oxygen because of excessive period during which complete combustion will occur.
23	Formula was accepted, and was later found to be a 10-minute cartridge (complete combustion occurs during a period of 10 minutes).
24	This formula, having no combustible material (100 per cent diatomaceous earth), was used for experimental comparison only.
25	Used for experimental comparison only.

ADDITIONAL FORMULAE.

The authors devised additional formulae keeping in mind the cheapness of the material, ease of handling it, deterioration of strength in storage, etc. The percentages in each formulae were arbitrarily chosen. These formulæ, Nos. 26 to 54, are given below:

Additional formulae devised.

Formula No.	Composition.
26	75 per cent wood pulp, 25 per cent starch.
27	60 per cent wood pulp, 20 per cent starch, 20 per cent paraffin.
28	50 per cent wood pulp, 50 per cent starch.
29	50 per cent wood pulp, 50 per cent naphthalene.
30	75 per cent wood pulp, 25 per cent naphthalene.
31	60 per cent wood pulp, 20 per cent naphthalene, 20 per cent paraffin.
32	50 per cent cotton, 50 per cent starch.
33	60 per cent cotton, 20 per cent starch, 20 per cent paraffin.
34	50 per cent wood pulp, 50 per cent ground bachite (activated anthracite coal).
35	75 per cent wood pulp, 25 per cent charcoal.
36	50 per cent diatomaceous earth, 50 per cent ground bachite.
37	50 per cent diatomaceous earth, 50 per cent naphthalene.
38	50 per cent diatomaceous earth, 50 per cent gas oil.
39	75 per cent diatomaceous earth, 25 per cent gas oil.
40	50 per cent wood pulp, 50 per cent gas oil.
41	75 per cent wood pulp, 25 per cent gas oil.
42	50 per cent diatomaceous earth, 50 per cent residuum oil.
43	75 per cent diatomaceous earth, 25 per cent residuum oil.
44	50 per cent wood pulp, 50 per cent residuum oil.
45	75 per cent wood pulp, 25 per cent residuum oil.
46	50 per cent wood pulp, 50 per cent sulphur.
47	50 per cent diatomaceous earth, 50 per cent sulphur.
48	50 per cent diatomaceous earth, 50 per cent flour.
49	75 per cent wood pulp, 25 per cent paraffin.
50	50 per cent diatomaceous earth, 50 per cent 200-mesh Pittsburgh coal dust.
51	75 per cent wood pulp, 25 per cent 200-mesh Pittsburgh coal dust.
52	75 per cent wood pulp, 25 per cent aluminum dust.
53	75 per cent diatomaceous earth, 25 per cent vaseline.
54	75 per cent wood pulp, 25 per cent vaseline.

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Reasons for discarding certain formulae.

Of these formulae, the following were discarded for the reasons given below:

Formula No.	Reason.
32 and 33	Ingredients not easily mixed (cotton).
34 and 35	Cartridge would not detonate in cannon (bachite).
40 and 41	Wood pulp would not absorb gas oil in this proportion.
44	Wood pulp would not absorb residuum oil in this proportion.

From the curves for rate of evaporation other curves were plotted (percentage composition against oxygen held per gram) to show the oxygen per gram that cartridges containing different percentages of wood pulp or of diatomaceous earth have at zero time, at the end of 5 minutes, at end of 10 minutes, and at end of 15 minutes. These curves were used to calculate compositions that would have complete combustion, approximately without excess or deficiency of oxygen, at the end of 5, 10, or 15 minutes, according to the time curve chosen.

Oxygen required per gram for complete combustion.

Combustible material:	Grams.
Paraffin	3.456
Wood pulp	1.370
Cellulose	1.185
Naphthalene	3.000
Residuum oil	3.211
Charcoal	2.667
Gas oil	3.465
Aluminum	0.889
Vaseline	3.429
Sulphur	1.000
Pittsburgh coal dust	2.390

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

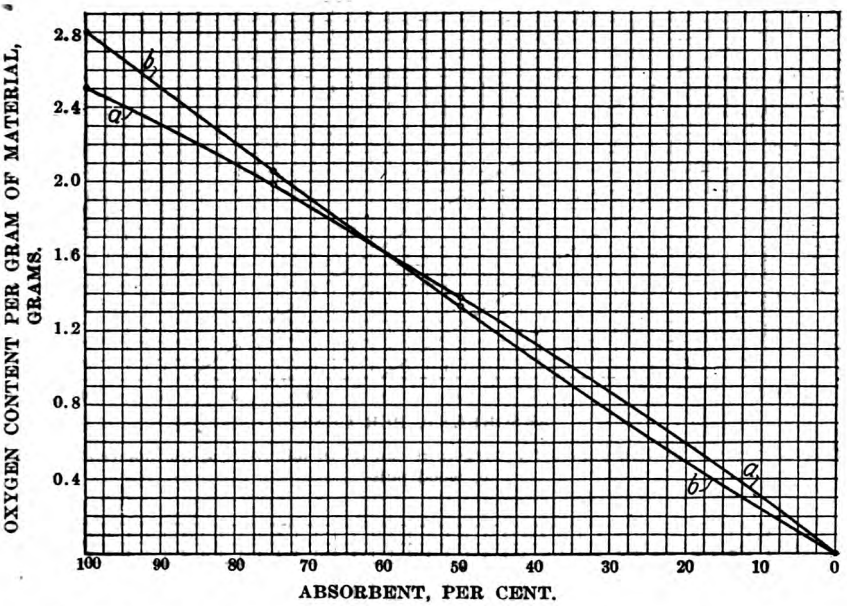


FIGURE 8.—Calculation curves for oxygen for zero time: *a*, diatomaceous earth; *b*, wood pulp.

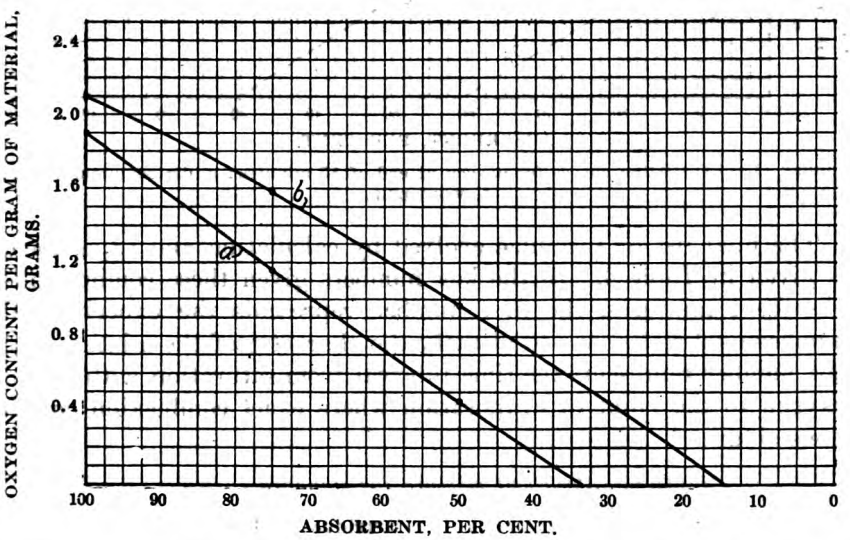


FIGURE 9.—Calculation curves for oxygen at end of 5 minutes: *a*, diatomaceous earth; *b*, wood pulp.

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

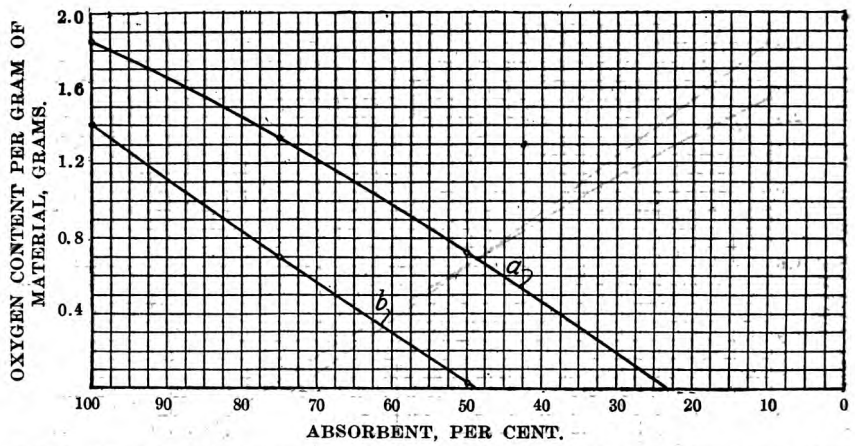


FIGURE 10.—Calculation curves for oxygen at end of 10 minutes: *a*, diatomaceous earth; *b*, wood pulp.

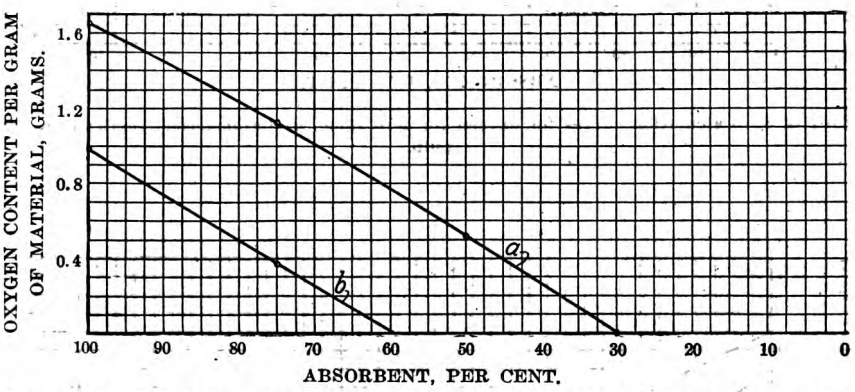


FIGURE 11.—Calculation curves for oxygen at end of 15 minutes: *a*, diatomaceous earth; *b*, wood pulp.

The final list of formulae evolved by calculation and experiment is given in Table 6. In the key numbers given these combustible-absorbent mixtures, the first number represents the experimental number used and serves to identify the character of the mixture, the last number represents the time interval from saturation with liquid oxygen to the point of evaporation where exact combustion conditions obtain.

TABLE 6.—*Absorbent mixture for standard cartridges.*

Cartridge 13A5:
63.2 per cent diatomaceous earth.
36.8 per cent paraffin.

Cartridge 13A10:
67.6 per cent diatomaceous earth.
32.4 per cent paraffin.

Cartridge 13A15:
71.0 per cent diatomaceous earth.
29.0 per cent paraffin.

Cartridge 14A15:
25.1 per cent paraffin.
18.8 per cent wood pulp.
56.1 per cent diatomaceous earth.

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

TABLE 6.—*Absorbent mixture for standard cartridges*—Continued.

Cartridge 14A10:
22.0 per cent paraffin.
16.5 per cent wood pulp.
61.5 per cent diatomaceous earth.

Cartridge 14A15:
16.9 per cent paraffin.
12.7 per cent wood pulp.
70.4 per cent diatomaceous earth.

Cartridge 23A10:
100 per cent wood pulp.

Cartridge 26A5:
19.9 per cent starch.
80.1 per cent wood pulp.

Cartridge 26A10:
18.8 per cent starch.
56.6 per cent wood pulp.
24.6 per cent diatomaceous earth.

Cartridge 26A15:
15.9 per cent starch.
47.7 per cent wood pulp.
36.4 per cent diatomaceous earth.

Cartridge 27A5:
41.0 per cent wood pulp.
13.6 per cent starch.
13.6 per cent paraffin.
31.8 per cent diatomaceous earth.

Cartridge 27A10:
34.0 per cent wood pulp.
11.3 per cent starch.
43.4 per cent diatomaceous earth.
11.3 per cent paraffin.

Cartridge 27A15:
50.8 per cent diatomaceous earth.
29.6 per cent wood pulp.
9.8 per cent starch.
9.8 per cent paraffin.

Cartridge 28A10:
29.8 per cent wood pulp.
29.8 per cent starch.
40.4 per cent diatomaceous earth.

Cartridge 28A15:
28.1 per cent starch.
28.1 per cent wood pulp.
43.8 per cent diatomaceous earth.

Cartridge 29A5:
87.5 per cent wood pulp.
12.5 per cent naphthalene.

Cartridge 29A10:
23.5 per cent wood pulp.
23.5 per cent naphthalene.
53.0 per cent diatomaceous earth.

Cartridge 29A15:
22.0 per cent wood pulp.
33.0 per cent naphthalene.
56 per cent diatomaceous earth.

Cartridge 30A10:
48.3 per cent wood pulp.
16.1 per cent naphthalene.
35.6 per cent diatomaceous earth.

Cartridge 30A15:
41.1 per cent wood pulp.
13.7 per cent naphthalene.
45.2 per cent diatomaceous earth.

Cartridge 31A5:
5.9 per cent naphthalene.
5.9 per cent paraffin.
88.2 per cent wood pulp.

Cartridge 31A10:
10.2 per cent naphthalene.
10.2 per cent paraffin.
30.8 per cent wood pulp.
48.8 per cent diatomaceous earth.

Cartridge 31A15:
8.9 per cent naphthalene.
8.9 per cent paraffin.
26.9 per cent wood pulp.
55.3 per cent diatomaceous earth.

Cartridge 35A5:
13.2 per cent charcoal.
86.8 per cent wood pulp.

Cartridge 35A10:
16.5 per cent charcoal.
49.5 per cent wood pulp.
34.0 per cent diatomaceous earth.

Cartridge 35A15:
14.0 per cent charcoal.
42.0 per cent wood pulp.
44.0 per cent diatomaceous earth.

Cartridge 37A5:
40.2 per cent naphthalene.
59.8 per cent diatomaceous earth.

Cartridge 37A10:
35.4 per cent naphthalene.
64.6 per cent diatomaceous earth.

Cartridge 37A15:
31.6 per cent naphthalene.
68.4 per cent diatomaceous earth.

Cartridge 38A5:
37.2 per cent gas oil.
62.8 per cent diatomaceous earth.

Cartridge 38A10:
32.8 per cent gas oil.
67.2 per cent diatomaceous earth.

Generated on 2024-09-29 23:29 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

TABLE 6.—*Absorbent mixture for standard cartridges*—Continued.

Cartridge 38A15:
29.2 per cent gas oil.
70.8 per cent diatomaceous earth.
Cartridge 42A5:
38.7 per cent residuum oil.
61.3 per cent diatomaceous earth.
Cartridge 42A10:
34.1 per cent residuum oil.
65.9 per cent diatomaceous earth.
Cartridge 42A15:
30.4 per cent residuum oil.
69.6 per cent diatomaceous earth.
Cartridge 45A5:
11.7 per cent residuum oil.
88.3 per cent wood pulp.
Cartridge 45A10:
15.7 per cent residuum oil.
47.3 per cent wood pulp.
37.0 per cent diatomaceous earth.
Cartridge 45A15:
13.4 per cent residuum oil.
40.3 per cent wood pulp.
46.3 per cent diatomaceous earth.
Cartridge 46A5:
21.1 per cent sulphur.
78.9 per cent wood pulp.
Cartridge 46A10:
30.6 per cent sulphur.
30.6 per cent wood pulp.
38.8 per cent diatomaceous earth.
Cartridge 46A15:
28.9 per cent sulphur.
28.9 per cent wood pulp.
42.2 per cent diatomaceous earth.
Cartridge 47A5:
62.8 per cent sulphur.
42.2 pe rcent diatomaceous earth.
Cartridge 47A10:
55.3 per cent sulphur.
44.7 per cent diatomaceous earth.
Cartridge 47A15:
49.4 per cent sulphur.
50.6 per cent diatomaceous earth.
Cartridge 48A5:
59.9 per cent flour.
40.1 per cent diatomaceous earth.
Cartridge 48A10:
52.8 per cent flour.
47.2 per cent diatomaceous earth.
Cartridge 48A15:
47.1 per cent flour.
52.9 per cent diatomaceous earth.
Cartridge 49A5:
11.2 per cent paraffin.
88.8 per cent wood pulp.
Cartridge 49A10:
15.5 per cent paraffin.
46.5 per cent wood pulp.
38.0 per cent diatomaceous earth.
Cartridge 49A15:
13.2 per cent paraffin.
39.6 per cent wood pulp.
47.2 per cent diatomaceous earth.
Cartridge 50A5:
45.2 per cent standard 200-mesh coal dust.
54.8 per cent diatomaceous earth.
Cartridge 50A10:
39.8 per cent standard 200-mesh coal dust.
60.2 per cent diatomaceous earth.
Cartridge 50A15:
35.5 per cent standard 200-mesh coal dust.
64.5 per cent diatomaceous earth.
Cartridge 51A5:
13.3 per cent standard 200-mesh coal dust.
86.7 per cent wood pulp.
Cartridge 51A10:
16.7 per cent standard 200-mesh coal dust.
50.0 per cent wood pulp.
33.3 per cent diatomaceous earth.
Cartridge 51A15:
14.1 per cent standard 200-mesh coal dust.
42.4 per cent wood pulp.
43.5 per cent diatomaceous earth.
Cartridge 52A5:
22.1 per cent aluminum dust.
77.9 per cent wood pulp.
Cartridge 52A10:
19.4 per cent aluminum dust.
58.3 per cent wood pulp.
22.3 per cent diatomaceous earth.
Cartridge 52A15:
16.3 per cent aluminum dust.
49.1 per cent wood pulp.
34.6 per cent diatomaceous earth.
Cartridge 53A5:
37.4 per cent vaseline.
62.6 per cent diatomaceous earth.

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

TABLE 6.—*Absorbent mixture for standard cartridges*—Continued.

Cartridge 53A10:
33. 0 per cent vaseline.
67.0 per cent diatomaceous earth.
Cartridge 53A15:
29.1 per cent vaseline.
70.9 per cent diatomaceous earth.
Cartridge 54A5:
11.9 per cent vaseline.
88.1 per cent wood pulp.
Cartridge 54A10:
15.8 per cent vaseline.
47.6 per cent wood pulp.
36.6 per cent diatomaceous earth.
Cartridge 54A15:
13.5 per cent vaseline.
40.5 per cent wood pulp.
46.0 per cent diatomaceous earth.
Cartridge 55A5:
100 per cent sawdust.

COMPARATIVE TESTS OF LIQUID-OXYGEN EXPLOSIVES.

TRAUZL LEAD-BLOCK TESTS.

In the preliminary work it was thought that the Trauzl lead-block test could best be used for determining the comparative strength on liquid-oxygen explosives. Numerous drawbacks and difficulties were encountered in the course of these tests, and dependence later was placed on other means—notably the ballistic pendulum—but a number of lead-block tests were run.

CONDITIONS OF TEST.

A description of the regular Trauzl lead-block tests, as carried out at the explosives laboratory of the Bureau of Mines at Pittsburgh, Pa., may be found in Technical Paper 186.[2] The tests with liquid oxygen necessarily differed in a number of respects. The explosive charges were inclosed in asbestos, pasteboard, or other poorly conducting material instead of tin foil. The tamping used was not sand, as in the regular tests, but a cast block of plaster of Paris with a vent hole extending its length. This change in stemming was required by the necessity for a free outlet for the evaporating oxygen. The weight of tamping varied from 25 to 35 grams, instead of 50 c. c. or 71 grams as in the regular tests. The temperature of the blocks in every test was different from 15° C.

RESULTS OF TEST.

Although the tests made can not be compared logically with tests of other explosives, such as the nitroglycerin dynamites, nevertheless they serve for comparison of the results produced by different liquid-oxygen explosives in which the ingredients were varied. The results are given in Table 7.

[2] Howell, S. P., and Tiffany, J. E., Methods of routine work in the explosives laboratory of the Bureau of Mines, Tech. Paper 186, Bureau of Mines, 1918.

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:29 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

TABLE 7.—*Fourteen Trauzl lead-block tests of liquid-oxygen explosives.*

Test No.	Absorbent mixture No.	Insulation. Character.	Insulation. Weight (grams).	10-gram charge includes insulator, yes or no?	Weight of plaster of Paris stemming (grams).	Time from dipping container to firing (minutes).	Electric detonator No.	Igniter.	Per cent of oxygen in liquid air used.	Expansion (c. c.).	Remarks.
1	1	Asbestos	12.0	No	25.0	1	.....	Yes	33.0	.....	Did not explode.
2	1	do	12.0	No	25.0	1	6	.....	40.0	8	Borehole cold after shot.
3	1	do	12.0	No	25.0	1	6	.....	40.0	9	Most of shell of electric detonator recovered.
4	1	do	12.0	No	25.0	1	6	.....	40.0	10	Do.
5	1	do	12.0	No	32.5	½	8	.....	50.0	80	Borehole enlarged uniformly entire distance.
6	[1]	do	12.0	.....	25.0	.....	8	.....	.....	4	To test effect of No. 8 electric detonator.
7	[2]	do	12.0	.....	25.0	.....	8	.....	40.0	21	To test effect of evaporation alone.
8	21	do	12.0	No	25.0	1	8	.....	55.0	52	Incomplete detonation.
9	1	do	12.0	No	25.0	1	8	.....	55.0	147	End of detonator recovered.
10	1	do	12.0	No	25.0	1	6	.....	98.0	384	Complete detonation. See photograph of block. Pl. VI, 66.
11	22	do	12.0	No	25.0	1	6	.....	98.0	41	Incomplete detonation.[3]
12	14	Manila paper	1.2	Yes	38.0	1	6	.....	98.0	243	Complete detonation.
13	14	Asbestos	12.0	No	25.0	2	.....	Yes	98.0	0	Tamping blew out, fairly loud report.
14	14	do	12.0	No	25.0	2	6	.....	98.0	156	Complete detonation.

[1] Diatomaceous earth saturated with water.

[2] Diatomaceous earth.

[3] Detonator was not imbedded in charge properly.

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

DISCUSSION OF RESULTS.

From these Trauzl lead-block tests certain conclusions may be drawn. Table 7 shows that with mixture No. 1 the enlargement increased with increasing percentages of oxygen in the liquid air until, when 98 per cent liquid oxygen was used, the enlargement was of 384 c. c. This result was so unusual—an equal weight of 40 per cent nitroglycerin dynamite produces an enlargement of only 278 c. c.—that the block was sawed in two. (See Plate III, *B*, p. 20.) Evidently it is necessary for good results that the liquid air be of high oxygen content. (Compare tests 1 and 2 in ballistic pendulum.) Certain mixtures are more sensitive than others that differ only in combustible material. In test 12, where manila paper was used as insulation, the charge was more nearly under the conditions of regular tests, as the manila paper occupied little space. Comparison of the results of test 12 with test 14, in which the only differences were in the insulators and the weight of tamping, shows that the method of charging largely influences the results. It is worthy of note that the two trials made with electric igniters, a device that sets off the charge by means of flame alone, gave no enlargement of the cavity in the lead block.

As previously stated, the difficulties encountered in conducting these tests were great because of the smallness of the charge, and from the differences in conditions the results were never comparable with those of regular tests of nitroglycerin explosives.

BALLISTIC PENDULUM TESTS.

A method of testing the strength of an explosive, which is gaining many adherents because of its practical value, is the ballistic pendulum.[3] It was thought that this test might serve well for a comparative study of liquid-oxygen explosives, because cartridges 2¼ inches in diameter may be used. Various mixtures based on the evaporation curves for cartridges of this size were made. Mixtures were calculated that would, under the conditions of insulation, still contain enough oxygen at the end of 15 minutes to suffice for the combustion of all combustible matter, even that of the corrugated pasteboard insulation and cheesecloth wrapper, with the production of carbon dioxide and water.

Table 8 gives the results of the ballistic pendulum tests.

[3] For a description of the ballistic pendulum, see Technical Paper 186, Bureau of Mines.

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

TABLE 8.—*Eight ballistic pendulum tests of liquid-oxygen explosives.*

Test No.	Absorbent mixture No.	Insulation. Kind.	Insulation. Weight (grams).	Weight of plaster of Paris stemming (pounds)	Time from dipping to firing shot (minutes).	Time from dipping till just enough oxygen for exact combustion (minutes).	Electric detonator No.	Per cent of oxygen in liquid.	Total weight of explosive, including insulator and liquid (grams)	Swing (inches)	Unit-deflective charge (grams)
1	1	Corrugated pasteboard.	55.0	1	1	.....	8	55.0	424.0	4.33	328
2	1	.....do.....	38.5	1	1	.....	6	98.0	282.0	4.72	200
3	3	.....do.....	60.0	1	10	15	6	98.0	346.0	5.34	217
4	4	.....do.....	58.0	1	10	15	6	98.0	308.0	4.90	211
5	9	.....do.....	55.0	1	10	15	6	98.0	324.0	4.94	220
6	14	.....do.....	36.0	1	10	15	6	98.0	220.0	3.60	205
7	12	.....do.....	40.0	1	10	1	6	98.0	228.0	3.10	246
8	4	.....do.....	38.0	1	10	15	6	98.0	211.0	3.32	213

The unit-deflective charge is that weight of the explosive which gives a swing equal to that given by 227 grams of 40 per cent nitroglycerin dynamite.
Unit swing for 227 grams of 40 per cent nitroglycerin dynamite was 3.35 inches.

The apparent deflection of the ballistic pendulum by 1 gram of the following materials when used as liquid-oxygen explosive is shown below.

Apparent deflection of ballistic pendulum.

Substance:	Inch.	Substance—Continued.	Inch.
Paraffin	0.108	Coal dust	0.087
Naphthalene	.092	Vaseline	.110
Gas oil	.097	Wood pulp	.045
Residuum oil	.090	Starch	.045
Sulphur	.031	Charcoal	.077
Flour	.035	Aluminum	.051

Later, upon the adoption of the paper-toweling cartridge as standard, additional ballistic-pendulum tests were made, with this style of cartridge, of the formulae given in Table 6.

Evaporation tests were first run with cartridges 13–A–10, 26–A–10, 27–A–15, and 38–A–10, in the ballistic-pendulum cannon, to compare the rate of evaporation in this cannon with that in coal. The evaporation rate in the cannon proved to be faster and, for exact combustion, the life of the cartridges was only 80 per cent of that in coal.

Results of these ballistic-pendulum tests are given in Table 9. The strength of the cartridge, as compared with 40 per cent nitroglycerin dynamite, and the unit deflective charge were calculated. The specific gravity of each cartridge, the weight equivalent to the volume of a stick of 40 per cent dynamite, the deflection by this weight, and the strength by volume, compared with 40 per cent dynamite, were also calculated. From the deflections found, the deflection per gram of each individual ingredient was calculated, and from these values the calculated deflection for each formula was determined to serve as a comparison with the actual deflection found.

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

TABLE 9.—*Liquid-oxygen explosives.*

Number.	Cartridges 1½ by 6½ inches.				Ballistic pendulum tests.					Comparative strength.	Volumetric comparisons.				Rate of detonation.	
	Composition.	O_2 required per gram of dope (grams).	Weight of cartridge plus 6-gram wrapper (grams).	Weight plus oxygen (grams).	Time of firing (minutes).	Deflection (inches).	Calculated deflection (inches).	Unit deflective charge (grams).	Strength compared to 40 per cent dynamite.	Calculated deflection per gram of material (inch).	Specific gravity of liquid O_2 cartridge.	Weight volume of ½-pound stick dynamite (grams).	Deflection by this weight (inches).	Strength by volume compared with dynamite.	Rate, meters per second.	Measurement between marks on lead plates (cm.).
13A5	63.2 per cent diatomaceous earth		98	222	4	3.50	3.89	204	1.11							
	36.8 per cent paraffin	1.27								Paraffin.	1.23	198	3.13	0.47	3,500	10.5
13A10	67.6 per cent diatomaceous earth		99	210	8	3.21	3.46	220	1.03							
	32.4 per cent paraffin	1.12								0.108	1.16	188	2.87	.90	3,828	9.6
13A15	71.0 per cent diatomaceous earth		90	182	12	2.84	2.76	206	1.10							
	29.0 per cent paraffin	1.00									1.09	163	2.53	.80	4,083	9.0
14A5	25.1 per cent paraffin		88	188	4	3.26	3.17	186	1.22	Wood pulp .045						
	18.8 per cent wood pulp	1.13									1.04	168	2.91	.90	4,711	7.7
	56.1 per cent diatomaceous earth															
14A10	22.0 per cent paraffin		95	190	8	2.93	2.96	210	1.08							
	16.5 per cent wood pulp	.99									1.05	170	2.62	.82	5,404	6.5
	61.5 per cent diatomaceous earth															
14A15	16.9 per cent paraffin		88	157	12	2.30	2.11	220	1.03							
	12.7 per cent wood pulp	.76									.87	140	2.05	.64	Misfire.	
	70.4 per cent diatomaceous earth															
23A10	100 per cent wood pulp	1.37	61	144	8	2.76	2.74	177	1.28		.80	129	2.46	.76	Misfire.	
26A5	19.9 per cent starch		78	181	4	3.51	3.49	166	1.37							
	80.1 per cent wood pulp	1.33								Starch	1.00	161	3.13	.97	Misfire.	
26A10	18.8 per cent starch		85	171	8	3.11	2.89	185	1.23							
	56.6 per cent wood pulp	1.00								.045	.95	153	2.78	.86	Misfire.	
	24.6 per cent diatomaceous earth															
26A15	15.9 per cent starch		93	174	12	.00	2.66	0•	.00							
	47.7 per cent wood pulp	.89	92	172	5	.63			.63		.96	155	2.95	.92	Misfire.	
	36.4 per cent diatomaceous earth															

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

TABLE 9.—*Liquid-oxygen explosives*—Continued.

Number.	Composition.	Cartridges 1½ by 6½ inches. O_2 required per gram of dope (grams).	Weight of cartridge plus 6-gram wrapper (grams).	Weight plus oxygen (grams).	Ballistic pendulum tests. Time of firing (minutes).	Deflection (inches).	Calculated deflection (inches)	Unit deflective charge (grams).	Strength compared to 40 per cent dynamite.	Comparative strength. Calculated deflection per gram of material (inch).	Volumetric comparisons. Specific gravity of liquid O_2 cartridge.	Weight volume of ½-pound stick dynamite (grams).	Deflection by this weight (inches).	Strength by volume compared with dynamite.	Rate of detonation. Rate, meters per second.	Measurement between marks on lead plates (cm.).
27A5	41.0 per cent wood pulp															
	13.6 per cent starch		88	193	4	3.33	3.45	186	1.22							
	13.6 per cent paraffin	1.20									1.07	172	2.97	.92	4,176	8.8
	31.8 per cent diatomaceous earth															
27A10	34.0 per cent wood pulp															
	11.3 per cent starch		95	191	8	3.19	3.11	197	1.18							
	11.3 per cent paraffin	.99									1.06	171	2.85	.90	Misfire	
	43.4 per cent diatomaceous earth															
27A15	50.8 per cent diatomaceous earth															
	29.6 per cent wood pulp		97	182	12	2.60	2.75	227	1.00							
	9.8 per cent starch	.86									1.01	165	2.32	.72	Misfire	
	9.8 per cent paraffin															
28A10	29.8 per cent wood pulp		97	173	8	.56	2.60	360	.63							
	29.8 per cent starch	.76	105	187	3	.00					.96	155	1.39	.43		
	40.4 per cent diatomaceous earth															
28A15	28.1 per cent starch		99	173	12	.00	2.50	0c	.00							
	28.1 per cent wood pulp	.72	104	181	5	.00					.96	155	2.64	.82		
	43.8 per cent diatomaceous earth															
29A5	87.5 per cent wood pulp		67	170	4	3.17	3.41	192	1.32							
	12.5 per cent naphthalene	1.57									.94	152	2.83	.90	Misfire	
29A10	23.5 per cent wood pulp		92	188	8	2.84	3.07	210	1.08	Naphthalene.						
	23.5 per cent naphthalene	1.03									1.04	168	2.53	.80	Misfire	
	53.0 per cent diatomaceous earth															

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

29A15	22.0 per cent wood pulp		93	184	12	.83	2.90	710	.32	.092						
	22.0 per cent naphthalene	.96	94	195	5	.00	Fuse used.				1.02	166	2.96	.96	Misfire.	
	56.0 per cent diatomaceous earth															
30A10	48.3 per cent wood pulp		82	176	8	2.75	3.06	206	1.10							
	16.1 per cent naphthalene	1.14									.98	157	2.45	.76	2,745	14.2
	35.6 per cent diatomaceous earth															
30A15	41.1 per cent wood pulp		83	165	12	2.70	2.64	198	1.15							
	13.7 per cent naphthalene	.97									.91	147	2.41	.75	Misfire.	
	45.2 per cent diatomaceous earth															
31A5	5.9 per cent naphthalene		66	169	4	3.44	3.41	161	1.41							
	5.9 per cent paraffin	1.59									.94	151	3.07	.95	4,187	9.3
	88.2 per cent wood pulp															
31A10	10.2 per cent naphthalene															
	10.2 per cent paraffin		91	190	8	3.37	3.17	182	1.25							
	30.8 per cent wood pulp	1.08									1.05	170	3.00	.93	Misfire.	
	48.8 per cent diatomaceous earth															
31A15	8.9 per cent naphthalene															
	8.9 per cent paraffin		93	182	12	2.86	2.83	205	1.11							
	26.9 per cent wood pulp	.94									1.01	163	2.55	.80	Misfire.	
	55.3 per cent diatomaceous earth															
35A5	13.2 per cent charcoal		65	163	4	3.22	3.20	164	1.39	Charcoal.						
	86.8 per cent wood pulp	1.54									.90	146	2.87	.90	Misfire.	
35A10	16.5 per cent charcoal		88	187	8	3.00	3.08	202	1.13							
	49.5 per cent wood pulp	1.12								.077	1.01	167	2.68	.83	Misfire.	
	34.0 per cent diatomaceous earth															
35A15	14.0 per cent charcoal		88	173	12	1.21	2.61	465	.49							
	42.0 per cent wood pulp	.95									.96	155	1.08	.34	Misfire.	
	44.0 per cent diatomaceous earth															
37A5	40.2 per cent naphthalene		99	218	4	3.90	3.66	179	1.27							
	59.8 per cent diatomaceous earth	1.21									1.21	195	3.48	1.08	Misfire.	
37A10	35.4 per cent naphthalene		97	201	8	3.06	3.15	213	1.07							
	64.6 per cent diatomaceous earth	1.06									1.12	180	2.73	.85	Misfire.	
37A15	31.6 per cent naphthalene		96	188	12	2.41	2.74	251	.91							
	68.4 per cent diatomaceous earth	.95									1.04	168	2.15	.67	Misfire.	
38A5	37.2 per cent gas oil		106	242	4	3.43	3.82	227	1.00							
	62.8 per cent diatomaceous earth	1.29								Gas oil.	1.34	216	3.06	.95	4,941	7.9
38A10	32.8 per cent gas oil		96	205	8	3.05	3.05	217	1.05							
	67.2 per cent diatomaceous earth	1.14								.097	1.14	183	2.72	.84	4,575	8.5
38A15	29.2 per cent gas oil		97	196	12	2.70	2.75	234	.97							
	70.8 per cent diatomaceous earth	1.01									1.03	175	2.41	.75	4,128	9.5

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

TABLE 9.—*Liquid-oxygen explosives*—Continued.

Number.	Composition.	Cartridges 1½ by 6½ inches.			Ballistic pendulum tests.					Comparative strength.	Volumetric comparisons.				Rate of detonation.	
		O_2 required per gram of dope (grams).	Weight of cartridge plus 6-gram wrapper (grams).	Weight plus oxygen (grams).	Time of firing (minutes).	Deflection (inches)	Calculated deflection (inches)	Unit deflective charge (grams).	Strength compared to 40 per cent dynamite.	Calculated deflection per gram of material (inch).	Specific gravity of liquid O_2 cartridge.	Weight volume of ½-pound stick dynamite (grams).	Deflection by this weight (inches).	Strength by volume compared with dynamite.	Rate, meters per second.	Measurement between marks on lead plates (cm.).
42A5	38.7 per cent residuum oil		103	231	4	3.32	3.52	225	1.01	Residuum oil.						
	61.3 per cent diatomaceous earth	1.24									1.28	206	2.96	.92	3,900	10.2
42A10	34.1 per cent residuum oil		108	227	8	3.32	3.32	220	1.03							
	65.9 per cent diatomaceous earth	1.10								.090	1.25	202	2.96	.92	5,515	7.1
42A15	30.4 per cent residuum oil		113	225	12	2.83	3.10	255	.89							
	69.6 per cent diatomaceous earth	.98									1.24	201	2.52	.78	7,830	5.0
45A5	11.7 per cent residuum oil		69	176	4	3.39	3.28	167	1.36							
	88.3 per cent wood pulp	1.59									.98	157	3.03	.94	7,100	5.5
45A10	15.7 per cent residuum oil		99	213	8	3.52	3.51	194	1.17							
	47.3 per cent wood pulp	1.15									1.16	190	3.14	.97	3,900	10.1
	37.0 per cent diatomaceous earth															
45A15	13.4 per cent residuum oil		94	190	12	2.92	2.84	210	1.08							
	40.3 per cent wood pulp	1.01									1.15	170	2.60	.81	6,315	6.2
	46.3 per cent diatomaceous earth															
46A5	21.1 per cent sulphur		73	167	4	2.99	3.07	180	1.26							
	78.9 per cent wood pulp	1.29								Sulphur.	.91	150	2.67	.83		
46A10	30.6 per cent sulphur		101	177	8	2.70	2.35	210	1.08							
	30.6 per cent wood pulp	.73								.031	.98	158	2.41	.75		
	38.8 per cent diatomaceous earth															
46A15	28.9 per cent sulphur		97	167	12	2.27	2.30	237	.96							
	28.9 per cent wood pulp	.69									.93	150	2.05	.64		
	42.2 per cent diatomaceous earth															

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

47A5	62.8 per cent sulphur		115	191	4	2.22	2.23	277	.82							
	37.2 per cent diatomaceous earth	.63									1.06	170	1.98	.61		
47A10	55.3 per cent sulphur		115	183	8	2.00	1.97	295	.77							
	44.7 per cent diatomaceous earth	.55									1.01	163	1.78	.55		
47A15	49.4 per cent sulphur		113	173	12	.99	1.74	557	.40							
	50.6 per cent diatomaceous earth	.49	112	172	5	2.35					.96	155	.88	.27		
48A5	59.9 per cent flour		105	183	4	2.23	2.20	264	.86							
	40.1 per cent diatomaceous earth	.71								Flour.	1.01	143	1.99	.62		
48A10	52.8 per cent flour		105	174	8	.42	1.86		.17							
	47.2 per cent diatomaceous earth	.62	104	173	8	.85				.035	.97	155	.37	.11		
48A15	47.1 per cent flour		99	158	12	.11	1.63		.05							
	52.9 per cent diatomaceous earth	.56	106	169	5	.00	Electric spitter used.				.87	140	.09	.02		
49A5	11.2 per cent paraffin		65	167	4	3.42	3.36	158	1.44							
	88.8 per cent wood pulp	1.60									.93	150	3.04	.95	4,661	8.4
49A10	15.5 per cent paraffin		84	183	8	3.10	3.17	191	1.19							
	46.5 per cent wood pulp	1.17									1.01	163	2.77	.86	5,160	7.6
	38.0 per cent diatomaceous earth															
49A15	13.2 per cent paraffin		86	173	12	2.44	2.86	230	.99		.96	155	2.18	.68	Misfire.	
	39.6 per cent wood pulp	1.00														
	47.2 per cent diatomaceous earth															
50A5	45.2 per cent standard 200-mesh Pittsburgh coal dust		102	213	4	3.33	3.77	204	1.11	(a)						
	54.8 per cent diatomaceous earth	1.08									1.18	190	3.36	1.04	Misfire.	
50A10	39.8 per cent standard 200-mesh Pittsburgh coal dust		94	190	8	2.80	3.25	218	1.04							
	60.2 per cent diatomaceous earth	.95								.087	1.05	170	2.90	.90	Misfire.	
50A15	35.5 per cent standard Pittsburgh coal dust		88	176	12	1.21	2.71	463	.49							
	64.5 per cent diatomaceous earth	.85	99	185	5	1.53					.97	158	2.42	.75	Misfire.	
51A5	13.3 per cent standard Pittsburgh coal dust		68	171	4	3.20	3.44	182	1.25							
	86.7 per cent wood pulp	1.51									.95	153	3.07	.95	Misfire.	
51A10	16.7 per cent standard Pittsburgh coal dust															
	50.0 per cent wood pulp		84	180	8	3.05	3.10	191	1.19		.99	160	2.77	.86	Misfire.	
	33.3 per cent diatomaceous earth	1.08														

a Standard Pittsburgh coal dust.

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:32 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

TABLE 9.—*Liquid-oxygen explosives*—Continued.

Number.	Composition.	Cartridges 1½ by 6½ inches.			Ballistic pendulum tests.					Comparative strength.	Volumetric comparisons.				Rate of detonation.	
		O_2 required per gram of dope (grams).	Weight of cartridge plus 6-gram wrapper (grams).	Weight plus oxygen (grams).	Time of firing (minutes).	Deflection (inches)	Calculated deflection (inches)	Unit deflective charge (grams).	Strength compared to 40 per cent dynamite.	Calculated deflection per gram of material (inch).	Specific gravity of liquid O_2 cartridge.	Weight volume of ½-pound stick dynamite (grams).	Deflection by this weight (inches).	Strength by volume compared with dynamite.	Rate, meters per second.	Measurement between marks on lead plates (cm.).
51A15	14.1 per cent standard Pittsburgh coal dust															
	42.4 per cent wood pulp		89	176	12	.98	2.78	581	.39							
	43.5 per cent diatomaceous earth	.92	89	172	6	1.63					.98	158	2.48	.77	Misfire.	
52A5	22.1 per cent aluminum dust		76	172	4	3.51	3.52	158	1.44							
	77.9 per cent wood pulp	1.26								Aluminum.	.95	154	3.14	.98	Misfire.	
52A10	19.4 per cent aluminum dust															
	58.3 per cent wood pulp		85	169	8	3.15	3.07	173	1.31							
	22.3 per cent diatomaceous earth	.97								.051	.94	151	2.81	.87	Misfire.	
52A15	16.3 per cent aluminum dust															
	49.1 per cent wood pulp		89	164	12	1.74	2.71	303	.75							
	34.6 per cent diatomaceous earth	.82	88	162	5	3.31					.91	146	1.55	.48	Misfire.	
53A5	37.4 per cent vaseline		93	212	4	3.23	3.83	212	1.07							
	62.6 per cent diatomaceous earth	1.28								Vaseline.	1.17	190	2.86	.90	7,800	5.1
53A10	33.0 per cent vaseline		96	205	8	2.96	3.48	222	1.02							
	67.0 per cent diatomaceous earth	1.13								.110	1.14	183	2.65	.82	7,830	5.0
53A15	29.1 per cent vaseline		95	191	12	3.03	3.03	205	1.12							
	70.9 per cent diatomaceous earth	1.00									1.06	170	2.70	.84	6,510	6.0
54A5	11.9 per cent vaseline		69	178	4	3.58	3.64	160	1.42							
	88.1 per cent wood pulp	1.62									.99	150	3.20	.99	8,344	4.7

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:33 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

54A10	15.8 per cent vaseline															
	47.6 per cent wood pulp															
	36.6 per cent diatomaceous earth	1.19	88	193	8	3.25	3.21	192	1.18		1.07	172	2.90	.90	5,935	6.6
54A15	13.5 per cent vaseline															
	40.5 per cent wood pulp		87	177	12	2.74	2.88	208	1.09							
	46.0 per cent diatomaceous earth	1.02									.98	158	2.44	.76	4,718	8.3
55A5	100 per cent sawdust														Misfire.	
	40 per cent nitroglycerin dynamite		227			3.22	3.22	227	1.00		1.40					
	Wrapper, paper toweling	1.18	6	13.1	Same in all cartridges.											

All cartridges detonated by No. 6 electric detonators; charges stemmed with 1 pound dry fire clay.

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

DISCUSSION OF RESULTS.

It will be seen that here again a high percentage of oxygen in the liquid (air) used is essential. All the mixtures compare favorably with 40 per cent nitroglycerin dynamite, and the fact that 10 minutes had elapsed between dipping the cartridges and firing the shots, certainly shows that the explosives can be used in cartridges as small as 2¼ inches.

The requirement of having the explosives last a reasonable length of time after removal from the liquid oxygen is of the utmost importance for permitting a number of holes to be fired simultaneously. For this reason the evaporation curves were originally run and mixtures were calculated that would attain, allowing for evaporation, their exact combustion point at the end of a certain time. The time interval, 15 or 20 minutes, was not chosen because it was all that could be desired, but because the tests showed it to be about all that could be obtained, without sacrifice of strength, at the present stage of the investigation. The ballistic pendulum tests of these mixtures calculated from the evaporation curves were certainly favorable as mixtures 3, 4, 9, and 14—all 15-minute mixtures—had the great strength shown by their low unit-deflective charges of 217, 211, 220, and 205 grams as compared with 227 grams of 40 per cent nitroglycerin dynamite. It should be pointed out that the smaller the unit-deflective charge, the greater the "material getting" strength of the explosive. Even mixture No. 12, which never had, after one minute, enough oxygen for the complete combustion of the combustible matter to carbon dioxide and water, at the end of 10 minutes showed a unit-deflective charge of 246 grams. The only drawback to mixture No. 12 seems to be that the deficiency of oxygen would cause the formation of considerable carbon monoxide, a poisonous gas. No similar test of mixture No. 1 after the 10-minute interval was made because of the similarity of mixtures Nos. 1 and 12.

Analysis of the later ballistic-pendulum results, given in Table 9, indicate the following as regards the more recent formulae given in Table 6. The presence of certain substances, such as wood pulp, starch, charcoal, flour, and coal dust, tends to render the mixtures insensitive to detonation even when confined. The presence of hydrocarbons, such as paraffins, naphthalene, vaseline, gas oil, and residuum oil, renders the explosives mixtures more sensitive to detonation, and even tends to counteract the insensitizing effect of wood pulp, etc. Aside from those mixtures that contained insensitive materials, all of these explosive mixtures compare favorably, weight for weight, with 40 per cent nitroglycerin dynamite. As bearing on charging conditions, the strength comparison, volume for volume, with 40 per cent dynamite is from 75 to 100 per cent.

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

DETONATION OF UNCONFINED CARTRIDGES.

One of the usual requirements of an explosive is that it shall detonate freely when suspended in air, and some experiments to determine whether these mixtures would meet that requirement were made. The results and the conditions of the tests are given in Table 10.

TABLE 10.—*Seven detonations of unconfined cartridges.*

Test No.	Absorbent mixture No.	Insulation, double telescope.		Time to exact combustion conditions (minutes).	Time from dipping to firing (minutes).	Per cent oxygen in liquid.	Length of cartridge outside (cm.).	Diameter of cartridge outside (cm.).	Electric detonator No.	Remarks.
		Kind.	Weight (grams).							
1	23	Asbestos....	12.0	2.0	0.5	98.0	5.9	2.4	6	Did not detonate at all.
2	1	.....do.....	12.0	2.5	1.0	98.0	3.7	2.4	6	Complete detonation.
3	13	Corrugated pasteboard	52.0	22.0	35.0	98.0	19.0	5.7	6	Practically complete detonation.
4	14	Manila paper	13.5	6.0	6.0	98.0	19.0	3.2	6	Detonated 2 inches; then burned.
5	14	.....do.....	18.5	10.0	10.0	98.0	19.0	3.8	6	Do.
6	20	.....do.....	15.0	.0	1.5	98.0	19.0	3.2	6	½ cartridge detonated, then burned.
7	14	Corrugated pasteboard	40.0	3.0	11.0	98.0	18.0	3.2	6	¾ cartridge detonated, then burned.

Tests of mixtures adopted later in the investigation resulted as follows:

Results of further tests of unconfined cartridges.

Cartridge No.	Results.
37A5.....	Most of cartridge detonated. Small amount of wrapper left burning.
49A5.....	Partial detonation only.
50A5.....	Do.

DISCUSSION OF RESULTS.

The tests were by no means as complete as desirable, but the results and the data found in rate of detonation and small lead-block tests are all the information available at present. From these tests it appears that for detonation of unconfined cartridges there should be at least 20 per cent crude oil or paraffin or other similar hydrocarbon in the absorption mixture.

Mixture No. 23, in which the combustible absorbent material was wood pulp, did not detonate at all; mixture No. 14, consisting of 65 per cent diatomaceous earth, 20 per cent paraffin, and 15 per cent wood pulp, and mixture No. 20, containing 51 per cent diatomaceous earth, 34 per cent paraffin, and 15 per cent wood pulp, detonated incompletely. In the later tests, mixture 49–A–5, containing 11.2 per cent paraffin and 88.8 per cent wood pulp, and mixture 50–A–5, con-

Generated on 2024-09-29 23:30 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

taining 45.2 per cent standard 200-mesh Pittsburgh coal dust and 54.8 per cent diatomaceous earth, detonated only partly. On the other hand, those mixtures (Nos. 1, 13, 37–A–5) containing hydrocarbons and diatomaceous earth gave complete detonation. These results bear out the author's observations on the results of the ballistic-pendulum tests that certain materials, as wood pulp, coal dust, etc., render the explosives insensitive. This is unfortunate, particularly as to wood pulp, which is both a combustible material and an absorbent and would otherwise be ideal.

FUSE AND DETONATORS FOR LIQUID-OXYGEN EXPLOSIVES.

In the preliminary tests, all evidence indicated that electric detonators were the only reliable means of detonating liquid-oxygen explosives. As the work progressed, however, and information showing the effect of various materials, as components of the mixtures, in causing sensitiveness or insensitiveness to detonation, became available, it was felt that additional experiments were desirable. Furthermore, investigations of developments in European practice disclosed that fuse, electric igniters, and liquid-oxygen detonators were being used with liquid-oxygen explosives.

Experiments were therefore made to determine the sensitiveness to detonation of some representative liquid-oxygen explosive mixtures when fired with safety fuse, with fulminate detonators, and with liquid-oxygen detonators.

The work of preparing and testing these liquid-oxygen detonators will be described, first of all, because it gives indications as to the sensitiveness of certain liquid-oxygen absorbing mixtures to detonation. These detonators were made by pressing the compositions into common black-powder electric igniters with a small rod, closing the end with a cotton wad and then punching a number of small holes through the pasteboard walls to admit the liquid oxygen to the composition. The composition formulae which were tested were as follows:

Composition formulae of igniter tested.

Formula No.	Composition.	Formula No.	Composition.
1	66⅔ antimony sulphide, 33⅓ wood pulp.	5	Ground cork.
2	66⅔ lead sulphocyanate, 33⅓ wood pulp.	6	66⅔ ground cork, 33⅓ aluminum dust.
3	50 ground cork, 50 antimony sulphide.	7	66⅔ ground cork, 33⅓ naphthalene.
4	50 ground cork, 50 lead sulphocyanate.	8	66⅔ ground cork, 33⅓ residuum oil.

Detonators of these various compositions were soaked in liquid oxygen and tested for detonation immediately after withdrawal. No time limit was placed on them as in use they would be protected from high evaporation losses by the liquid-oxygen cartridge in which they were imbedded. Numbers 1 to 4, inclusive, did not detonate

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

and were discarded, but numbers 5 to 8, inclusive, detonated completely.

The data from tests of the various liquid-oxygen explosive mixtures with different detonators and igniters appear below:

Cartridge 13A5 (63.2 per cent diatomaceous earth, 36.8 per cent paraffin):

Test No. 1.—Cartridge, loaded in ballistic pendulum cannon and stemmed with 1 pound of dry fire clay, ignited with safety fuse.

Complete detonation was obtained.

Test No. 2.—Cartridge, loaded as above but ignited by liquid-oxygen detonator, formula 6.

Complete detonation was obtained.

Cartridge 31A5 (5.9 per cent naphthalene, 5.9 per cent paraffin, 88.2 per cent wood pulp):

Test No. 1.—Cartridge loaded as above and ignited with fuse.

Detonation not obtained; cartridge ignited and burned.

Test No. 2.—Cartridge loaded as above and ignited with liquid-oxygen detonator, formula 7.

Complete detonation was obtained.

Cartridge 49A5 (11.2 per cent paraffin, 88.8 per cent wood pulp):

Test No. 1.—Cartridge loaded as above and ignited with fuse.

Cartridge started to burn, then detonated.

Test No. 2.—Cartridge loaded as above and fired with liquid-oxygen detonator, formula 8.

Complete detonation was obtained following a delayed shot.

Cartridge 50A5 (45.2 per cent standard 200-mesh Pittsburgh coal dust, 54.8 per cent diatomaceous earth):

Test No. 1.—Cartridge loaded as above and fired with safety fuse.

No ignition or detonation was obtained.

Test No. 2.—Cartridge was loaded as above and fired with liquid-oxygen detonator, formula 7.

Cartridge burned.

Test No. 3.—Cartridge loaded as above and fired with liquid-oxygen detonator, formula 8.

Cartridge burned.

Test No. 4.—Cartridge loaded and fired with No. 6 fulminate electric detonator.

Complete detonation was obtained.

SUMMARY.

These tests demonstrated that liquid-oxygen explosive mixtures vary considerably in sensitiveness to detonation, and that some of them, when confined, may be detonated by means of safety fuse. In particular, the sensitizing effect of hydrocarbons as a component of such explosive mixtures was indicated and the desensitizing effect of wood pulp and coal dust was emphasized.

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

RATE OF DETONATION TESTS.

From the work with these mixtures Nos. 9 and 14 seemed to be the most favorable, consequently the rates of detonation were run on these samples, using the well-known method of Dautriche.[4]

The results are given in Table 11.

TABLE 11.—*Three rates of detonation tests of liquid-oxygen explosives.*

Test No.	Absorbent mixture No.	Insulation, corrugated pasteboard (grams).	Electric detonator No.	Weight of explosive, including corrugated pasteboard (grams).	Time to exact combustion point (minutes).	Time from dipping to firing (minutes).	Per cent oxygen in liquid.	Length of cartridge file (cm.).	Distance past center of Cordeau (cm.).	Rate of detonation per second (meters).	Diameter of cartridge (cm.).
1	9	52.0	6	314.5	15	10	98.0	12.0	8.5	3,031	5.7
2	9	52.0	6	314.5	15	10	98.0	12.0	8.4	2,996	5.7
3	14	52.0	6	307.8	15	10	98.0	11.0	6.8	3,433	5.7

Rate of detonation was obtained in each test by the Dautriche method, using 6-mm. Cordeau-Bickford fuse with a rate of detonation of 4,244 meters per second.

In these tests the explosive was in corrugated pasteboard insulators and was fired 10 minutes after removal from the dipping container; the liquid air contained 98 per cent oxygen; and the diameter of cartridges was 5.7 cm. or 2¼ inches. The cartridges were unconfined.

Later, July, 1920, rate of detonation tests were run on standard (paper towel) ½-inch cartridges with mixtures given in Table 6. As it had previously been found that many of these formulae gave explosives that would not detonate when unconfined, certain changes were made in the method of test. The cordeau Bickford fuse and lead plate were placed on the ground. The ends of the fuse crimped to the two detonators were held 6 inches apart by being run through holes drilled through small blocks of wood, the detonators projecting through the opposite side. The cartridge, after being dipped, was laid on these two detonators and covered carefully with a pile of loose dirt in such a way that it was not dislodged. The detonator ends were not inserted into the liquid-oxygen cartridge because of the low temperature and consequent solidity of the cartridge. The cordeau Bickford fuse was standardized and found to have a rate of 5,147 meters per second. Results of the tests are given in Table 9.

DISCUSSION OF RESULTS.

The average rate of detonation of mixture No. 9 was 3,014 meters per second, and of mixture No. 14, 3,433 meters per second. These rates are not very high, but compare favorably with the rates of the ammonia dynamites, the rate of detonation of a 40 per cent strength ammonia dynamite cartridge 1¼ inches in diameter being 3,157

[4] Study of the velocity of detonation, by Comey, Arthur M. Report 7th Int. Cong. App. Chem., p. 31.

Generated on 2024-09-29 23:38 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

meters per second, and the average rate of permissible explosives being about 3,000 meters per second.

Under the modified conditions of test that were later adopted the rates of detonation were considerably higher. These higher rates may have been due to the confinement used in attempting to insure detonation. Here again the desensitizing effect of various ingredients, as wood pulp, starch, and coal dust, is evident, and the sensitiveness of mixtures containing hydrocarbons, particularly liquid hydrocarbons, is demonstrated.

SMALL LEAD-BLOCK TEST.

A small lead-block test was made with mixture No. 1; 100 grams of explosive were used exclusive of the corrugated pasteboard wrapper. The cartridge was 3 inches long and 1½ inches diameter, and when fired one minute after withdrawal from the liquid oxygen gave a compression of 17.50 mm.

Small lead-block tests were tried with mixtures 3 and 4 but the charges failed to detonate.

DETONATION OF UNCONFINED EXPLOSIVE PROBABLY NOT ESSENTIAL.

As stated previously, one of the requirements usually demanded for an explosive is that it shall detonate when freely suspended in air—probably because of the danger incidental to unexploded cartridges remaining in holes. Manifestly, any of these liquid-oxygen explosives would not be dangerous if left unexploded in a drill hole, as after a lapse of 30 minutes all of the oxygen would have evaporated and the material would no longer be an explosive. Furthermore, ordinary explosives are charged in a drill hole in cartridges 8 inches long, and if the hole is irregular or loose material happens to fall from the side of the hole, the different portions of the charge may be separated by either an air space, when the cartridges stick in irregular holes, or by inert material when material falls from the side of the hole. With these liquid-oxygen explosives, if the practice used by the Bureau of Mines in different physical tests and outside in field tests is followed, separation of portions of the charge is unlikely. It has been the practice of the bureau to make the outside corrugated pastboard insulation tube long enough to accommodate the entire charge used in a hole and of a diameter that will fit the drill hole snugly. As the separate 8-inch cartridges with the inside pasteboard insulators surrounding them are previously made to slip easily into the outside insulation, there is little danger of the cartridge lacking confinement or failing to transmit the detonation to the next cartridge. Where more than one inner cartridge (8-inch) is used, the inside insulators are open at both ends, except the last one which is closed at the top. The detonator is put in the last

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

cartridge inserted, and the legs of the detonator or electric blasting cap extend through the closed end of the last inside insulator. In this way the separate cartridges are always in contact, and the only material separating the absorbent explosive material of the adjoining cartridges is several layers of cheesecloth. If these layers between cartridges should tend to stop the detonation, the authors believe that it would suffice to saturate the cheesecloth, at the ends of the cartridge, with crude oil or other liquid hydrocarbons. Certainly the fact that after a certain lapse of time the charge in a drill hole ceases to be an explosive, owing to evaporation of the oxygen, is a point favoring these explosives in comparison with those ordinarily used.

With the adoption of the simpler paper-towel cartridge, an entirely different set of charging conditions have to be considered. The relative safety of these explosives still holds, but to increase efficiency in use, by preventing waste of labor through misfires, it is essential that the explosives should be sensitive enough to detonate under the usual charging conditions. As with paper-towel cartriges the charging conditions are similar to those when dynamite or permissible explosives are used, it is essential that these liquid-oxygen explosives detonate when unconfined. This conclusion is more or less borne out by comparison of the results recorded in Table 9 with misfires obtained in the 1919 to 1921 field tests (p. 37). As the hydrocarbons—such as paraffin, vaseline, gas oil, residuum oil, or naphthalene—present in liquid-oxygen explosive mixtures tend to make the explosives more sensitive to detonation, it would seem that only those formulæ should be recommended. On this basis, therefore, any mixture containing any considerable proportion of wood pulp, starch, flour, or coal dust is unsatisfactory. The following formulæ may be recommended:

TABLE 12.—*Formulae for liquid-oxygen explosives.*

Key No.	Diatomaceous earth.	Paraffin.	Residuum oil.	Gas oil.	Vaseline.	Wood pulp.
13A5	63.2	36.8				
13A10	67.6	32.4				
13A15	71.0	29.0				
14A5	56.1	25.1				18.8
14A10	61.5	22.0				16.5
38A5	62.8			37.2		
38A10	67.2			32.8		
38A15	70.8			29.2		
42A5	61.3		38.7			
42A10	65.9		34.1			
42A15	69.6		30.4			
45A5			11.7			88.3
45A10	37.0		15.7			47.3
45A15	46.3		13.4			40.3
53A5	62.6				37.4	
53A10	67.0				33.0	
53A15	70.9				29.1	
54A5					11.9	88.1
54A10	36.6				15.8	47.6
54A15	46.0				13.5	40.5

Generated on 2024-09-29 23:38 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Rice, who investigated the use of liquid-oxygen explosives by the Germans in occupied territory, says in correspondence: "* * * for taking the place of black powder, as in the iron mines of Lorraine, they have found it advantageous to use only fuse and wood pulp in order to obtain a slow heaving effect." This does not coincide with the experience of the authors, as unsatisfactory and unreliable results were obtained with wood pulp regardless of the means of firing.

TESTS TO DETERMINE SUITABILITY OF LIQUID-OXYGEN EXPLOSIVES FOR USE IN GASEOUS AND DUSTY COAL MINES.

FLAME TEST.

Some work was done on testing these liquid-oxygen explosives for safety in coal mines. In order to compare the height and duration of the flame with black powder and permissible explosives, a flame test was made of mixture No. 4, 100 grams being used as usual, including the corrugated pasteboard. As the length of explosive cartridge was only 7.5 cm., even though the cartridge was 5.7 cm. in diameter, the moment of exact combustion was five minutes after removal from the liquid oxygen, and the shot was fired at that time with a No. 6

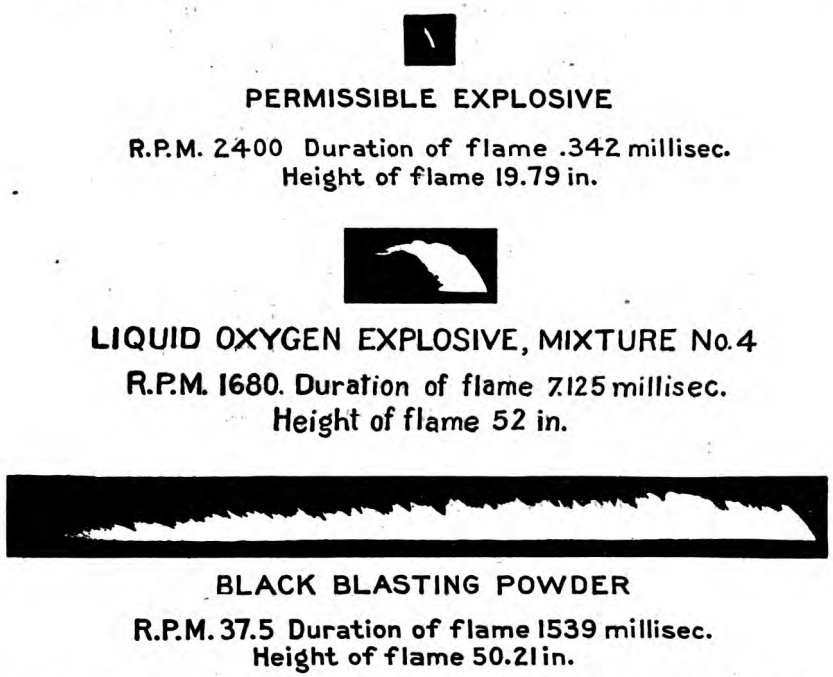


FIGURE 12.—Flames of permissible explosive, liquid-oxygen explosive, and black powder.

electric detonator. Figure 12 shows the photographs of the flames of the liquid-oxygen explosive, black powder, and a permissible explosive.

Generated on 2024-09-29 23:30 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

DISCUSSION OF RESULTS.

Comparison of the flames from a permissible explosive, the liquid-oxygen explosive, and black powder shows that although the duration of the flame is only about one two-hundredth that of black powder, nevertheless it is much greater than that of the permissible and of the same height as that of black powder.

TABLE 13.—*Height and duration of flame of three explosives.*

Explosive.	Speed of film per second (meters).	Height of flame (inches).	Duration of flame (milliseconds).
Permissible explosive	20	20	0.342
Liquid-oxygen explosive	14	52	7.125
Black blasting powder	$\frac{1}{16}$	50	1,539.000

Of the numerous explosives tested by the bureau to determine their permissibility for use in coal mines, none has ever become permissible whose flame exceeded one millisecond. The flame test therefore indicates that this liquid-oxygen explosive would not pass the tests for permissibility—a conclusion in line with the results obtained in the testing gallery, which are hereafter reported.

PRODUCTS OF COMBUSTION TEST.

A charge of 200 grams of liquid-oxygen explosive mixture No. 4 was fired in the Bichel pressure gauge; it was a 2¼-inch, or 57-mm., cartridge with corrugated pasteboard insulators. Manifestly it would have been useless to shoot this explosive in a vacuum, as ordinary explosives are tested, so it was fired in air at atmospheric pressure. The charge was fired 27 minutes after the cartridge had been withdrawn from the liquid oxygen, and at the moment there was a considerable deficiency of oxygen. The explosive was proportioned as follows:

Composition of liquid-oxygen explosive (Mixture No. 4).

Ingredient.	Grams.	Per cent.
Diatomaceous earth	33.9	17.0
Crude oil	6.3	3.2
Wood pulp	19.3	9.6
Cheesecloth	3.7	1.8
Corrugated pasteboard insulators	39.6	19.8
Liquid oxygen (moment of exact combustion)	97.2	48.6
Total	200.0	100.0

Generated on 2024-09-29 23:35 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

The gaseous products of combustion had the following composition:

Composition of gaseous products of combustion.

Gas.	Per cent.
Carbon dioxide (CO_2)	75.8
Oxygen (O_2)	1.3
Carbon monoxide (CO)	7.4
Hydrogen (H_2)	8.0
Methane (CH_4)	1.7
Nitrogen (N^2)	5.8
	100.0

GALLERY TESTS.[5]

Several gallery tests were made to determine whether these liquid-oxygen explosives would cause an explosion in mixtures of air, gas, and coal dust, or of air and coal dust alone. It was rather expected, as indicated in the flame test and as will be shown later in theoretical considerations, that the explosives would cause explosions of the mixtures of coal dust, gas, and air, and these expectations were realized.

A gallery test, No. 4, consisted in firing 680 grams of mixture No. 4, unstemmed, into a mixture of gas and air containing 4 per cent of methane and ethane, and of 20 pounds of bituminous coal dust, 100-mesh size, 18 pounds of which was placed on side shelves of gallery and 2 pounds in suspension. A No. 6 electric detonator was used, and the charge fired 10 minutes after the cartridge was withdrawn from the dipping container. A violent explosion of the gas and coal dust resulted, and flame was seen one-half the length of the 100-foot gallery. After the explosion much dust, badly charred, was found in the gallery.

A test, No. 3, was then made to see whether explosive mixture No. 4 would ignite coal dust alone. A unit-deflective charge—as previously determined with the ballistic pendulum—of 211 grams, with 1 pound of cast plaster of Paris stemming, was fired into the gallery, which had 20 pounds of bituminous dust on the side shelves and 20 pounds on a horse directly in front of the borehole of the cannon. A No. 6 electric detonator was used, and the charge was fired 10 minutes after the cartridge was removed from the liquid oxygen. A violent explosion of the coal dust resulted, and flame was seen 20 feet beyond the end of the 100-foot gallery.

TEMPERATURE CALCULATIONS.

As before mentioned, the results above were rather to be expected. It has been found that almost all detonating explosives having flame temperatures higher than 2,200° C. will ignite such gas and dust mix-

[5] For a description of gallery tests as conducted at the experiment station at Pittsburgh, see Technical Paper 186, Bureau of Mines.

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

tures, and the calculated flame temperatures of these liquid-oxygen explosives exceed this maximum, being 3,095° C. at the moment of exact combustion, and 2,309° C. at the end of 15 minutes from withdrawal from the liquid oxygen, when there is a deficiency of oxygen. In these thermochemical calculations, much of the data for the low temperatures represented by liquid air and oxygen was not available and had of necessity to be assumed; but, inasmuch as by far the largest range of temperature was at points where data are available, the calculations are interesting and serve at least as a guide.

Thermochemical calculation of the flame temperatures of liquid-oxygen explosive mixture No. 12 (40 per cent paraffin, 60 per cent diatomaceous earth) at moment of exact combustion.

1 Components.	2 Formula.	3 Composition (per cent).	4 Molecular weight.	5 Column 3 / Column 4.	6 Column 5 / 0.0308
Paraffin	$C_{24}H_{50}$	10.42	338	0.0308	1.00
Diatomaceous earth	SiO_2	15.63	60	.2605	8.46
Cellulose [a]	$C_6H_{10}O_5$	16.92	162	.1044	3.40
Oxygen	O_2	55.88	32	1.7462	56.70
Nitrogen	N_2	1.15	28	.0411	1.33

[a] Cellulose represents cheesecloth wrapper and corrugated pasteboard insulators.

The following theoretical equation represents the detonation of the explosive.

$$C_{24}H_{50}+8.46\ SiO_2+3.4\ C_6H_{10}O_5+56.7\ O_2+1.33\ N_2=44.4\ CO_2+42.0\ H_2O+8.46\ SiO_2+1.33\ N_2.$$

Heats of formation of decomposition products:

CO_2	44.4	×94,300=	4,186,920
H_2O	42.0	×58,100=	2,440,200
Gas	87.73×	545=	47,813
			6,674,933
			1,146,036
			Q=5,528,897

Heats of formation of original constituents:

	1×	270,200=	270,200
	3.4×	230,400=	783,360
[6]	56.7×	1,599=	90,663
[6]	1.33×	1,363=	1,813
			1,146,036

Q=5,528,897 calories=heat of reaction.

[6] Heat of vaporization.

Generated on 2024-09-29 23:38 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Heat capacity of decomposition products of the reaction.

$C=A+b\ t$	
CO_2 44.4 × 6.26=277.944	44.4 ×0.0037t =0.1643t
H_2O 42.0 × 5.61=235.620	42.0 × .0033t = .1386t
SiO_2 8.46×11.8 = 99.828	8.46× .00236t= .0200t
N_2 1.33× 4.8 = 6.384	1.33× .0006t = .0008t
C=619.776	0.3237t

Substituting the above values of Q, a, and b in the general equation,

$$t=\frac{-a+\sqrt{a^2+4b\times Q}}{2b}$$

gives the value of t:

$$t=\frac{-619.776+\sqrt{(619.776)^2+4\times 0.3237\times 5,528,897}}{2\times 0.3237}=3,285^\circ\text{ C.}$$

As the initial substances of the reaction were at −190° C. instead of 0° C., as used in the computations, then the final temperature of explosion is given by:

$$t(^\circ\text{C.})=3,285-19=3,095^\circ\text{ C.}$$

Thermochemical calculations of the flame temperature of liquid-oxygen explosive mixture No. 12 (40 per cent paraffin, 60 per cent diatomaceous earth) at the end of 15 minutes from withdrawal from the liquid oxygen, when there is a deficiency of oxygen.

1 Components.	2 Formula.	3 Composition (per cent).	4 Molecular weight.	5 Column 3 / Column 4.	6 Column 5. / 0.0321
Paraffin	$C_{24}H_{50}$	13.38	338	0.0396	1.23
Diatomaceous earth	SiO_2	20.07	60	.3345	10.42
Cellulose	$C_6H_{10}O_5$	21.74	162	.1342	4.18
Oxygen	O_2	43.91	32	1.3722	42.75
Nitrogen	N_2	.90	28	.0321	1.00

The following theoretical equation represents the detonation of the explosive:

$$1.23\ C_{24}H_{50}+10.42\ SiO_2+4.18\ C_6H_{10}O_5+42.75\ O_2+N_2=51.65\ H_2O+10.42\ SiO_2+N_2+54.45\ CO+0.15\ CO_2.$$

Heats of formation of decomposition products:

CO_2	0.15×94,300=	14,145
CO	54.45×26,100=1,	421,145
H_2O	51.65×58,100=3,	000,865
Gas	107.25× 545=	58,451
		4,494,606
		1,365,138
	Q=3,	129,468

Heats of formation of original constituents:

1.23×270,200=		332,346
4.18×230,400=		963,072
[7] 42.75× 1,599=		68,357
[7] 1.00× 1,363=		1,363
		1,365,138

Q=3,129,468 calories=heat of reaction.

[7] Heat of vaporization.

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Heat capacity of the decomposition products of the reaction.

	$C=a+b\ t$	
CO_2	$0.15\times 6.26= 0.939$	$0.15\times 0.0037t = 0.0006t$
CO	$54.45\times 4.8 = 261.360$	$54.45\times 0.0006t = .0327t$
H_2O	$51.65\times 5.61 = 289.756$	$51.65\times 0.0033t = .1704t$
N_2	$1.00\times 4.80 = 4.800$	$1.00\times 0.0006t = .0006t$
SiO_2	$10.42\times 11.8 = 122.956$	$10.42\times 0.00236t = .0246t$
	679.811	.2289*t*

Substituting the above values of Q, a, and b in the general equation:

$$t=\frac{-a+\sqrt{a^2+4b\times Q}}{2b}$$

gives the value of t, the rise in temperature.

$$t=\frac{-679.811+\sqrt{(679.811)^2+4\times 0.2289\times 3,129,468}}{2\times 0.2289}=2,499^\circ\ C.$$

As the initial substances of the reaction were at —190° C. instead of 0° C., as assumed in the computations, then the final temperature of explosion is given by:

$$t(°C.)=2,499-190=2,309^\circ\ C.$$

It will be noted that the flame temperature is in both cases above 2,200° C. maximum, and is particularly high, 3,095° C., in exact combustion. It is interesting to note also the consequent lowering of the temperature of the flame by the deficiency of oxygen in the second case, for this offers a means of producing a liquid-oxygen explosive that will be safe in gas and dust mixtures. Consequently, the effect of adding to these explosives certain salts containing water of crystallization will now be considered.

By adding varying quantities of crystalline salts to mixture No. 14, mixtures Nos. 15, 16, and 17 were made. The thermochemical calculations for these, based on the assumption of complete combustion of the mixtures, give the following results:

Reduction of calculated flame temperature by addition of salts containing water of crystallization.

Mixture No.	Parts of salt added to 100 parts of mixture No. 14 to form given mixture.		Calculated flame temperature (° C.).
	$Al_2(SO_4)_3.18H_2O$.	$MgSO_4.7H_2O$.	
14	0	0	2,957
15	0	81.8	2,542
16	16	0	2,863
17	31.5	0	2,649

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

As the results show, even for mixtures with relatively high percentages of salts containing water of crystallization the flame temperatures are very high. In the calculations for mixture No. 12 it was shown how a deficiency of oxygen contributes to the lowering of the flame temperature; furthermore, an excess of oxygen in the liquid state should serve to decrease the temperature, because of the heat required for evaporation and for raising the temperature of the resulting gas. The flame temperature for a number of points of deficiency and excess of liquid oxygen in the cartridge of mixture 14 were calculated and the curve, Figure 13, shows graphically the results of these calculations.

The ordinate figures represent, read either way from zero, the deficiency or excess of oxygen as a percentage of what is required for exact combustion to carbon dioxide and water. The curve brings out the relatively greater effect of a deficiency of oxygen.

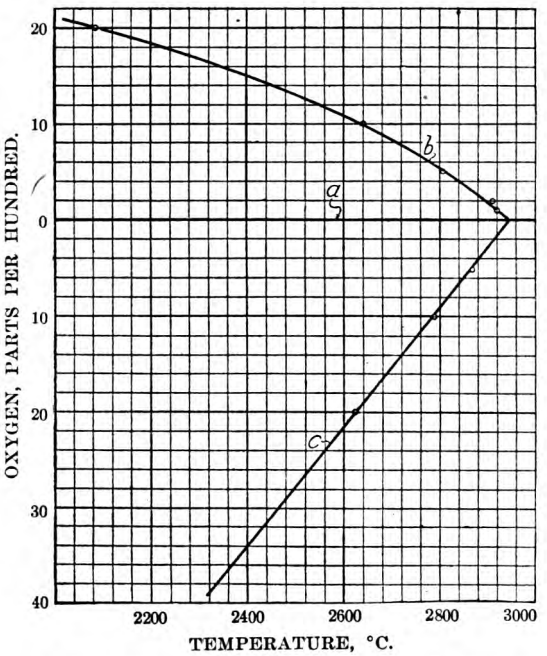


FIGURE 13.—Effect of deficiency and excess of oxygen on the temperature of explosion of a liquid-oxygen explosive: *a*, exact combustion; *b*, deficiency; *c*, excess.

Of course there is a limit to this deficiency of oxygen beyond which an explosive would not detonate; but it is certain that mixture No. 12, with a great deficiency of oxygen, detonated, and its calculated temperature at the end of 15 minutes was 2,309° C. as compared with 3,095° C. at the point of exact combustion.

DISCUSSION OF RESULTS.

However, as the amount of oxygen in a cartridge can hardly be gauged with accuracy, it would not be advisable to consider a liquid-oxygen explosive permissible when its safe use depended upon firing it with a certain deficiency of oxygen. Any modification of these explosives to render them permissible for use in gaseous and dusty coal mines should therefore take the form of added nonvolatile

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

substances, such as salts containing water of crystallization. If the explosives were to be judged permissible, it should only be after they passed the required tests throughout their entire range of explosibility, from deficiency to excess of oxygen.

In the formulae previously given (Nos. 14, 15, 16, and 17) the attempt was made to reduce flame temperatures by adding hydrated salts. Later when the author realized that sodium carbonate decahydrate ($Na_2CO_3.10H_2O$) had a much greater cooling effect than the salts previously used, a number of formulae were calculated to have a flame temperature below the 2,200° C. maximum previously mentioned. The data for these formulae follow:

Formulae of explosives with lower flame temperatures.

Formula No.	Composition.
P1	20.53 per cent diatomaceous earth; 13.68 per cent paraffin. (No. 12, old formula) 65.79 per cent $Na_2CO_3.10H_2O$. Dope, 0.473/1 O_2 req.; wrapper, 1.183/1 O_2 req. Calculated flame temperature, 1,956° C.
P2	29.03 per cent diatomaceous earth; 6.70 per cent wood pulp; 8.93 per cent paraffin. (No. 14, old formula) 55.34 per cent $Na_2CO_3.10H_2O$. Dope, 0.400/1 O_2 req.; wrapper, 1.183/1 O_2 req. Calculated flame temperature, 2,047° C.
P3	15.44 per cent diatomaceous earth; 10.30 per cent paraffin; 74.26 per cent $Na_2CO_3.10H_2O$. (No. 12, old formula with larger amount of $Na_2CO_3.10H_2O$ added than in P1.) Dope, 0.357/1 O_2 req.; wrapper, 1.183/1 O_2 req.
P4	22.74 per cent diatomaceous earth; 5.25 per cent wood pulp; 7.00 per cent paraffin; 65.01 per cent $Na_2CO_3.10H_2O$. (No. 14, old formula, with larger amount of $Na_2CO_3.10H_2O$ added than in P2.) Dope, 0.314/1 O_2 req.; wrapper, 1.183/1 O_2 req.
P5	(No. 37, old formula) 18.62 per cent diatomaceous earth; 18.62 per cent naphthalene; 62.76 per cent $Na_2CO_3.10H_2O$. (For permissibility.) Dope, 0.559/1 O_2 req.; wrapper, 1.183/1 O_2 req. Calculated flame temperature, 1,982° C.
P6	(No. 29, old formula) 11.12 per cent wood pulp; 11.12 per cent naphthalene; 77.76 per cent $Na_2CO_3.10H_2O$. (For permissibility.) Dope, 0.486/1 O_2 req.; wrapper, 1.183/1 O_2 req. Calculated flame temperature, 1,652° C.

Two tests were made with cartridges P1 and P2 in the steel gallery at the experimental mine at Bruceton, Pa., with the procedure of gallery test No. 1, as described on page 23 of Technical Paper 186. Cartridges of the standard size were used, loaded in a cannon and fired by No. 6 detonators into the gallery atmosphere, which contained 8 per cent gas. No ignition was obtained.

These formulæ were devised by using old formulæ Nos. 12, 14, 29, and 37, adding $Na_2CO_3.10H_2O$ and calculating the flame temperatures according to the method described in Bulletin 15,[8] page 16. Flame temperatures of formulæ P3 and P4 were not calculated, because the formulæ were devised by adding a little more $Na_2CO_3.10H_2O$ to formulæ P1 P2.

[8] Hall, Clarence, Snelling, W. O., and Howell, S. P., Investigations of explosives used in coal mines. Bull. 15, Bureau of Mines. 1912.

Generated on 2024-09-29 23:29 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

$Na_2CO_3.10H_2O$ was selected as the best hydrated salt to use because it is cheap, easy to obtain, and is the most efficient in cooling power. The reader should note that the cooling power per gram and not per gram-mole must be considered in determining efficiency.

Calculations and results indicate the possibility of preparing a liquid-oxygen explosive that would pass the tests for permissibility for use in gaseous and dusty coal mines. This subject would require considerable further investigation, however, before a final decision could be reached.

MISCELLANEOUS TESTS.

ANALYSIS OF LIQUID OXYGEN.

At two different times, when it was doubtful whether liquid oxygen or liquid air had been obtained, analyses were made by the assistant chemist, G. W. Jones. These analyses showed that the average composition of the liquid oxygen used in the tests was 97.7 per cent oxygen and 2.3 per cent nitrogen.

BALLISTIC PENDULUM TESTS USING NO. 8 DETONATOR.

In the tests made with the ballistic pendulum some of the 15-minute cartridges either did not detonate at all or gave a weak deflection, so it was thought advisable to try these tests again with a No. 8 electric detonator instead of a No. 6, and in each trial a detonation and satisfactory deflection was obtained.

DETONATION TESTS IN CANNON.

Tests were made in a cannon to determine whether detonation could be obtained by using liquid-oxygen detonators or a fuse. Results showed that all cartridges can not be detonated completely with liquid-oxygen or fuse detonators of the present size. Whether a liquid-oxygen detonator, a fuse, a No. 6 electric detonator, or a No. 8 detonator will produce a detonation depends on the composition of the cartridge.

TESTS UNDER WATER.

In order to determine whether a liquid-oxygen cartridge could be fired under water, a cartridge containing 75 per cent diatomaceous earth and 25 per cent residuum oil (old formula No. 43) was dipped and thrown into a shallow pond. About two minutes were allowed to elapse before firing. Complete detonation was obtained, which blew a large hole in the mud of the bottom of the pond, and threw a column of water high into the air.

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

INFLUENCE TESTS.

Influence tests[9] of a number of cartridges gave negative results. The cartridges were suspended, end to end, in air and 3 inches apart. In each test only part of the first cartridge detonated.

EFFECT OF MOISTURE ON THE DETONATION OF A WOOD-PULP CARTRIDGE.

In field test No. 19 the wood-pulp cartridges failed to detonate, although the detonator exploded satisfactorily. As the bore hole was very wet, it was decided to run tests to determine whether moisture was the cause of the failure to detonate. In the later tests, three 1½ by 6½ inch 23A10 cartridges were hung in a metal sampling can over the water for a period of 48 hours. The water was poured upon the can, and the cartridge left in the can during transportation to the experimental mine. The cartridges were dipped in liquid oxygen, and exploded with a No. 6 detonator in a cannon 8 minutes after dipping. Two of the cartridges detonated completely with a loud report. The third cartridge was not used. The test seems to show that water does not prevent the detonation of such a cartridge.

COMPARATIVE STRENGTH OF WOOD PULP AND SAWDUST AT VARIOUS TIMES.

Tests were run to determine how long the strength of wood pulp and of sawdust cartridges would last. The sawdust was a mixture of cypress, pine, and mahogany, and was of 14-mesh size. The curves, though irregular, showed that although the initial strength of the sawdust cartridge is greater than that of the wood-pulp cartridge, the strength of the latter keeps up longer.

TEST OF GERMAN DETONATOR.

Cartridge No. 50A5 (108 grams) was fitted with a German liquid-oxygen detonator and tested in the ballistic pendulum. A misfire resulted, because the German detonator failed to explode.

EVAPORATION TESTS TO DETERMINE THE EFFECT OF DECREASING THE DIAMETER OF THE CARTRIDGE UPON THE LIFE OF THE CARTRIDGE.

As some boreholes are for 1¼-inch cartridges, tests were run to determine whether the life or time of complete combustion would be decreased by decreasing the diameter of the cartridge. The results show that for some mixtures the life is not shortened appreciably; in other cases the time is shortened slightly; and in some the life is

[9] For a description of the explosion by influence tests, see Technical Paper 186, Bureau of Mines.

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

shortened considerably. For mixture 23A10 in a ¾-inch cartridge the life was shortened one-half. Most of the cartridges of the compositions tested could be used in the 1¾-inch size without so much incomplete combustion as to form too large a percentage of obnoxious gases. These formulae were chosen because they were used in the field tests.

EVAPORATION TESTS TO COMPARE DIFFERENT KINDS AND THICKNESSES OF WRAPPERS.

Evaporation tests with different varieties of wrappers and, usually, two different weights of each wrapper (determined by the number of times the wrapper was rolled about the cartridge), were run to determine the best variety of wrapper to use. A pure wood-pulp dope was used in each cartridge. The results appear below:

Results of evaporation tests to compare wrappers.

Wrapper No.	Material.	Weight used (grams).	Remarks.
a		8	Did not decrease life appreciably.
A	Kraft paper, 0.005 in. thick	16	Decreased life too much.
B	Manila paper, 0.004 in. thick	7	Do.
C	Kraft paper, 0.003 in. thick	5	Decreased life slightly.
D	News-print paper, 0.004 in. thick	6	Did not decrease life appreciably.
D		11	Decreased life too much.
E	Blotting paper, 0.023 in. thick	27	Do.
E		50	Do.
F	Asbestos, 0.029 in. thick	70	Increased life considerably.
F		144	Increased life decidedly.
G	Bond paper, 0.004 in. thick	9	Decreased life too much.
G		19	Did not decrease life appreciably.

It was thought that a wrapper could be found porous enough to admit liquid oxygen by longer soaking than usual, yet of a texture that would hold the oxygen for a greater length of time. With every wrapper but one, however, the life was decreased, and was not as long as that of a wood-pulp cartridge with the standard wrapper (paper towel). The one exception was an asbestos wrapper, which greatly increased the life because it required no oxygen for its own combustion. However, no doubt there are other kinds of wrappers that ought to be tested.

EFFECT OF ALLOWING CARTRIDGES CONTAINING PARAFFIN TO BE MORE THOROUGHLY MIXED AND HARDENED.

Cartridges Nos. 13A5 and 13A10, when made up, were placed in a warming oven, at about 50° C., to melt the paraffin. The cartridges were turned frequently so that the melted paraffin would thoroughly mix with the other ingredients. After the cartridges were removed they were allowed to cool, and were left lying in the laboratory several days to harden as much as possible. Some of the cartridges became so hard that the detonator was inserted with difficulty.

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Rate of detonation tests on two of the cartridges gave the results shown below:

Results of rate of detonation tests of two hardened cartridges.

Cartridge No.	Measurement between marks on lead plate (cm.).	Rate of detonation per second (meters).
13A5	7.5	5,229
13A10	6.1	6,429

The rates or detonation for the unhardened cartridges as given in the Table 9 on page 37 were: 13A5, 3,500; 13A10, 3,828 meters per second. Evidently there is great advantage, when increase of the rate of detonation is desired, in hardening the cartridges containing paraffin.

In ballistic pendulum tests of two 13A5 cartridges one, weighing 118 grams, gave a deflection of 4.89 inches; the other, weighing 112 grams, gave 4.31 inches. The results when compared with a deflection of 3.50 inches for an unhardened 98-gram cartridge indicate that the hardened cartridge is proportionately stronger, because the increase in strength or in deflection is greater than that accounted for by the increased weight of the cartridge; therefore it is advantageous to subject the paraffin cartridges to a process of hardening.

EFFECT OF SUBJECTING DOPE TO PRESSURE BEFORE MIXING INTO CARTRIDGES.

It is evident that if the dope of the cartridges were pressed together before being put into cartridge form a large quantity of it can be pressed into the space and a heavier and stronger cartridge made; but as the dope, if pressed too much, will not absorb enough oxygen, a medium between the two extremes produces the highest efficiency.

Pure wood pulp was first subjected to various pressures (500 to 4,833 pounds) and then made up into cartridges (23A10). Evaporation tests were run to determine what pressure permitted enough absorption of liquid oxygen. A pressure of about 500 pounds per square inch is the maximum that will permit the absorption of oxygen for complete combustion; it is the lowest pressure that could be recorded by the hydraulic ram used.

Three cartridges were then made from wood pulp subjected to a pressure of 500 pounds. In ballistic pendulum tests a number of 23A10 cartridges weighing 99 grams gave a deflection of 4.62 inches, and one weighing 128 grams gave 5.36 inches. An attempt to detonate a third cartridge, suspended in air, gave no results.

For pure diatomaceous earth subjected to pressure the results were negative. The diatomaceous earth stuck in a solid cake in the

Generated on 2024-09-29 23:35 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

bore of the machine, and had to be chiseled out if the pressures exceeded 10,000 pounds. With lower pressures, the material crumbled again on removal from the bore of the machine. One cartridge made from crumbled diatomaceous earth that had been subjected to a pressure of 9,666 pounds was used in an evaporation test. This cartridge was much heavier, and absorbed much more oxygen than the ordinary diatomaceous cartridge (No. 24); hence it would seem to be advantageous to put the diatomaceous earth cartridge under pressures up to 10,000 pounds, even though the dope does crumble on removal from the bore of the machine.

It was thought that by the use of a binder, such as oil, the diatomaceous earth might be made to stick together after removal from the bore of the pressure ram, but in trials using up to 30 per cent transformer or gas oil the results were unsatisfactory. A short length of the dope, with 30 per cent oil as binder, was finally removed from the bore, and made into a short cartridge that was used in an evaporation test.

This part of the investigation was not completed. It is suggested that perhaps if the diatomaceous earth were fitted with a wrapper—that is, made into cartridge form before being put in the bore of the machine—possibly it could be subjected to higher pressures and still be more easily removed from the bore. Of course, several such cartridges would have to be rewrapped to form one cartridge.

EFFECT OF LIQUID OXYGEN ON DETONATORS AND FUSE.

MATERIALS.

Four brands of commercial detonators were tested that had the composition shown below:

Composition of commercial detonators.

Key No.	Size No.	Average weight of charge (grams).	Composition.
M 2136.....	6	0.8280	Mercury fulminate, potassium chlorate, nitrocellulose, nitromannite.
M 1980.....	6	.7630	Mercury fulminate, potassium chlorate, nitrated vegetable ivory.
M 2209.....	6	.6863	Mercury fulminate, potassium chlorate, trinitromethylphenylnitramine.
M 54.....	7	1.4750	Mercury fulminate, potassium chlorate.

The fuse was the Anchor and Crescent brand (Ensign-Bickford), hard finished and cotton countered.

EFFECT OF LIQUID OXYGEN ON DETONATORS.

The tests were made in the vertical gallery with the front, or door, off. This gallery is built of 2-inch wood. A 150-c. c. beaker, containing 125 c. c. of liquid oxygen, was placed in the gallery, and the detonators were introduced into the oxygen by sliding them

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

down a 3-foot glass tube, 1½ cm. in diameter, inclined at an angle of 35°. This tube was so placed that the detonator was delivered just at the surface of the liquid oxygen. The observers remained behind the gallery and were protected by the 2 inches of wood in case of an explosion. Five detonators were immersed, at intervals of 20 seconds, and the beaker then set aside until the liquid oxygen had evaporated. This gave a beaker for each of the four brands.

Time required for total evaporation of liquid oxygen.

Key No.	Minutes.	Key No.	Minutes.
M 2136	18	M 2209	16
M 1980	15	M 54	19

RESULTS.

No physical effect of the liquid oxygen on the detonators could be observed.

When the detonators had regained room temperature three of each brand were shot in about 50 c. c. of liquid oxygen, contained in a 150-c. c. beaker, which was placed in a 10-gallon heavy metal waste can.

Effect of liquid oxygen on composition of detonators.

The outer fuse covering was stripped back, and the detonator so crimped as to allow the liquid oxygen to reach the primer charge. The fuse was stripped back ¾ inch in the No. 1 shots, 3 or 4 inches in the No. 2 shots, and ¾ inch in the No. 3 shots. The end of the fuse was ¼ inch back from the face of the primer charge in the No. 3 shots.

Key No.	Shot.	Fuse lit.	Explosion.	Remarks.
M2136	1	2:22:00	2:22:59	Flame visible simultaneously with explosion.
M2136	2	2:17:45	2:18:35	Six seconds of flame preceding explosion.
M2136	3	3:04:35	3:05:33	Short flame with explosion. Explosion violent. Glass pulverized.
M1980	1	2:31:40	2:32:30	Flame visible above can at moment of explosion. Fuse cover still burning when inspected after explosion.
M1980	2	2:36:10	2:39:13	Flare 12 seconds before explosion, with red flame up to explosion.
M1980	3	3:34:05	Misfire.	Fuse burned brightly for about 30 seconds. Detonator recovered intact. When the detonator was opened the fulminate was slightly darkened—as if it had been wet—at the ignition end. It was very much less sentitive (by hammer test) than usual. Two detonators that had not been immersed in liquid oxygen exploded well.
M2209	1	2:39:45	2:40:40	Fuse burning after explosion. Copious black smoke. Explosion was not violent, as indicated by the following: (*a*) Noise produced was less than usual. (*b*) Glass remained in fairly large pieces. (*c*) Fairly large fragments of the detonator were recovered. (*d*) A piece of unexploded primer charge (a disk of a diameter equal to the cross section of the detonator, ¼ inch thick at one edge and tapering to a knife-edge at the other) was recovered. In one of these detonators after immersion in liquid oxygen the fulminate was found to be less sensitive (by hammer test) than usual.
M2209	2	2:55:05	2:56:05	Flame with sputtering sparks for 20 seconds preceding explosion. Base of detonator intact after explosion.
M2209	3	3:54:55	3:56:03	Explosion good. Burned about 5 seconds preceding explosion.
M54	1	4:05:50	4:06:50	Flame and explosion simultaneous.
M54	2	4:00:35	4:01:43	Explosion, double in effect and not very violent, was preceded by 11 seconds of flame. Beaker contained twice as much liquid oxygen as usual.
M54	3	4:10:50	4:11:50	Sputtered after 15 seconds. Double explosion; beaker recovered only slightly cracked, and covered with snow. Twice as much liquid oxygen used as usual.

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

EFFECT OF LIQUID OXYGEN ON FUSE.

A V trough, 1 inch on each side, was constructed of 28-gauge galvanized iron. A piece of fuse 31 inches long was laid in this trough, one-half inch of diatomaceous earth placed over it, and the whole was wet through and frozen with liquid oxygen. Then the fuse was ignited, and the time required to burn was noted. A control piece of fuse was burnt in the trough after the trough had regained room temperature.

Length of fuse, 31 inches; time required to burn without liquid oxygen, 129 seconds; with liquid oxygen, 162 seconds. $\frac{162 \times 100}{129} = 126$ per cent.

CONCLUSIONS.

1. Detonators M2136 and M54 seem suitable for liquid-oxygen work, aside from the fuse question. These are not reinforced detonators.

2. Detonators M1980 and M2209 are not suitable for liquid-oxygen work. These are reinforced detonators.

3. Hard-finished, cotton-countered fuse requires 26 per cent more time to burn during immersion in liquid oxygen than without liquid oxygen. Apparently the desensitizing effect of the low temperature is greater than the effect of the added available oxygen.

4. Fuse and detonators are not recommended. The fuse covering makes too much flame—flame for a period as long as 15 seconds—when burning in the rich oxygen mixture.

5. No indication was observed of an increased sensitiveness of detonators immersed in liquid oxygen. In two tests the sensitiveness was decreased.

6. In the two tests where the sensitiveness was decreased the caps contained a small amount of mercury fulminate mixture, one having an added charge of tetryl and the other nitrated vegetable ivory. This decreased sensitiveness was probably due to the cold detonator condensing moisture on the fulminate after the liquid oxygen had evaporated, thus reducing the detonating efficiency of the priming charge or preventing its detonation.

FIELD TESTS OF LIQUID-OXYGEN EXPLOSIVES.

TESTS DURING 1917.

CHAMBERING SHOT AT MOREWOOD EXTENSION, PITTSBURGH, PA.

At Morewood Extension, Pittsburgh, Pa., in August, 1917, a soft shale was being excavated by steam shovels after being loosened by blasts of black powder. Holes 20 feet deep and about 5 inches diameter were "well-drilled" in the rock mass 20 feet from the face.

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

The usual procedure was first to chamber the hole by firing a charge of 2 or 3 pounds of 40 per cent nitroglycerin dynamite, unconfined, in the bottom of the hole. After this chambering the blast was made with black powder.

An attempt was made to chamber one of these holes with 2 pounds of liquid-oxygen explosive, mixture No. 14. The hole was dry, and the charge was not confined at all. The blast was rather unsatisfactory as giving positive information, for the results could not be determined exactly. The foreman in charge of the excavation did not think that the shot had accomplished what had been done in other holes with 40 per cent dynamite. That these liquid-oxygen explosives should be less efficient than the dynamites for unconfined shots is not surprising, as the rate of detonation of mixture No. 14 is 3,433 meters per second and that of 40 per cent nitroglycerin dynamite is 4,772 meters per second.

Plate IV, *A*, *B*, and *C*, shows the steps in preparing a liquid-oxygen cartridge, and Plate V, *A* and *B*, two periods during the chambering shot.

Results of the ballistic pendulum tests, however, seem to indicate that for blasts with charges confined by suitable tamping the liquid-oxygen explosive would be very efficient. Consequently some field tests were made under conditions where such charging conditions could be used, in the building-stone quarry of J. H. Ward & Sons, on Paulson Street, Pittsburgh, Pa.

BLOCK-HOLE AND BENCH SHOTS AT NO. 1 QUARRY OF J. H. WARD & SONS, PITTSBURGH, PA.

This quarry is in rock known commercially as blue rubblestone, a light gray sandstone with distinct horizontal planes of bedding and cleavage. The rock is not particularly hard, and the company has been using black powder to avoid shattering. The larger pieces thrown out by the shots are broken to the required sizes by wedges.

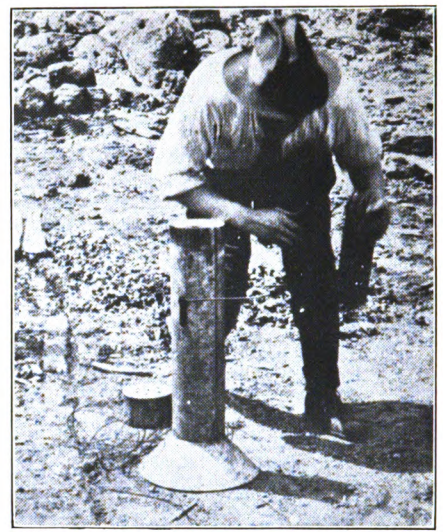
Two classes of shots are used in quarrying the stone. The larger shots are fired in holes 1½ inches diameter and 5 to 6 feet deep. These holes are drilled in the benches of the quarry, and charged with 500 to 750 grams of black powder. Then they are tamped with loose clay or broken stone—usually with a mixture of both. The purpose of these shots is to bring down the stone in rather large pieces which may later be worked up into building stone sizes by wedging, or, if the pieces are unusually large, by block-hole shots. These block-hole shots are in drill holes 1½ inches diameter, and from 18 to 30 inches in depth, and from 75 to 150 grams of black powder are used, tamped as before. Single shots are fired with

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

A. PUTTING CARTRIDGE OF LIQUID-OXYGEN EXPLOSIVE INTO INNER INSULATOR PREPARATORY TO CHARGING.

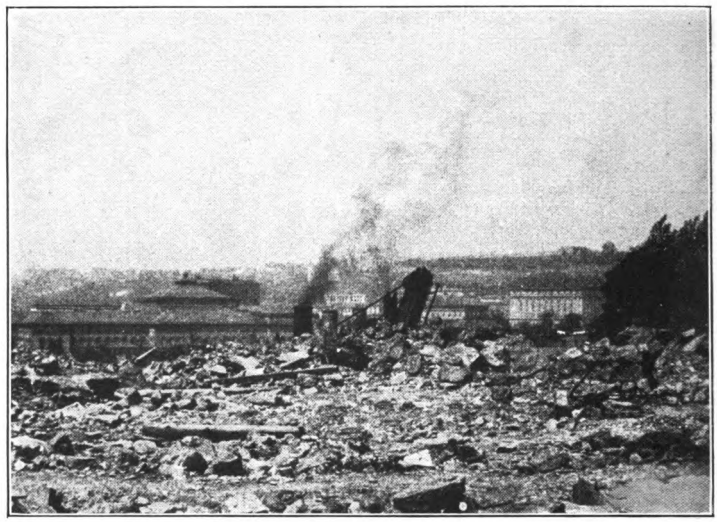
B. PUTTING OUTSIDE INSULATOR OVER CARTRIDGE PREPARATORY TO CHARGING.



C. CHARGE READY TO PLACE IN DRILL HOLE.

STEPS IN PREPARING LIQUID-OXYGEN CARTRIDGE.

Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN



A. JUST BEFORE CHAMBERING SHOT OF LIQUID-OXYGEN EXPLOSIVE.

B. AT MOMENT OF CHAMBERING SHOT, MOREWOOD EXTENSION, PITTSBURGH, PA.

Generated on 2024-09-29 23:29 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

safety fuse, but when several shots are to be fired simultaneously, No. 6 electric detonators are used.

The purpose of the test was to obtain information as to the power and characteristics of the liquid-oxygen explosives compounded. In these tests the cartridge proper was composed of a mixture of 20 per cent paraffin, 65 per cent diatomaceous earth, and 15 per cent wood pulp, packed in a double thickness of cheesecloth as wrapper. These cartridges were $\frac{7}{8}$ inch to 1 inch in diameter. Around these cheesecloth cartridges were fitted two telescoped corrugated pasteboard cylinders closed at alternate ends. The outside diameter of the cartridges, including the corrugated pasteboard insulators, was $1\frac{1}{2}$ inches, so they just fitted in the drill holes. The cheesecloth cartridges were soaked in the liquid oxygen to saturation (10 to 15 minutes) and were slipped into the insulators just prior to charging. In every charge the designated weight of explosive included the inner cartridge, plus the outside insulators, plus enough liquid oxygen for total combustion of all combustible material. The moment of firing, corresponding with exact combustion of the combustible material contained in the cartridge, was regulated according to evaporation tests conducted at the Bureau of Mines. No. 6 electric detonators were used in every test; they were placed in the cartridges before dipping.

In charging a hole the assembled explosive cartridge was placed at the bottom, then a wad of cotton was put on it. A brass tube, 3 mm. internal and $4\frac{1}{2}$ mm. outside diameter, extended from the cartridge proper to the top of the hole. Moist fire clay stemming was tamped in the hole, and the brass tube was withdrawn. Then the cartridge was ready to be fired at the proper interval for exact combustion. The brass tube provided an outlet for the escape of the evaporating oxygen during tamping and its withdrawal left a hole, in the moist stemming, which served a similar purpose until firing. The cotton wad above the cartridge was to prevent the moist fire clay from getting under and stopping the lower end of the brass tube.

The first shot was in a block of stone measuring about $2\frac{1}{2}$ by $3\frac{1}{2}$ by 4 feet. The drill hole measured $1\frac{1}{2}$ inches by 18 inches, and was about in the center of a $2\frac{1}{2}$ by 4-foot face. One hundred grams of the explosive were used, and the shot was fired 3 minutes after the cartridge was withdrawn from the liquid oxygen. The stone block was shattered badly and the fragments, some of them weighing 20 pounds, thrown to a distance of 50 feet. The hole was overcharged. Plate VI, *A* and *B* (p. 68), shows the block shot before and at the moment of firing.

Generated on 2024-09-29 23:29 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

The second shot was in a slightly larger block, which was free or largely free on four faces only and had a tight toe. Here the drill hole measured 1½ by 24 inches, and was charged with 70 grams of explosive. The shot was fired at the end of 2 minutes 50 seconds. The result was all that could be desired, as the rock was not shattered but broken up in large pieces. A peculiar feature of this shot was that the force of the explosion seemed to extend only to the bottom of the drill hole.

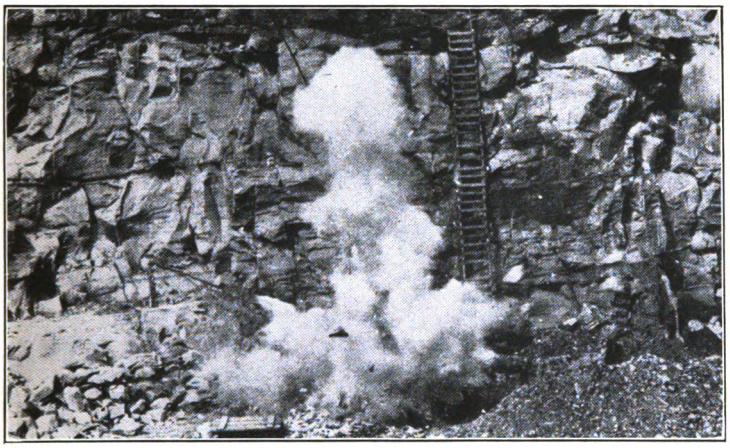
Two other holes were drilled in a bench of rock, loaded, and fired. Plate VI, *C*, shows the bench at the moment of shot firing. In shots of this kind the quarrymen were accustomed to use 700 grams of black powder in one hole and 475 grams in the other. The writer charged 440 grams of liquid-oxygen explosive in one hole and 320 grams in the other, connected the charges in series, and at the end of 6 minutes tried to fire them. Because of a break in the line the hole containing 440 grams of explosive was fired by itself at the end of 10½ minutes; it broke the rock in all directions. The other hole was fired at the end of 13 minutes. Because the interval before the firing of the small-diameter cartridge was unusually long, and because the first shot had opened fissures, the second shot did little work. Although the rock was not brought down, it was shattered so that it could be broken out with a crowbar. The rock was well broken back 2 feet behind the line of holes. Enough work was done on the rock to show that simultaneous firing of the holes at the end of 6 minutes would have given satisfactory results. The 760 grams of explosive broke 7,600 pounds of rock, equivalent to 10 pounds of rock per gram, or over 4,000 pounds of rock per pound of explosive.

TESTS DURING 1919, 1920, AND 1921.

Cartridges for these tests were made up in five different sizes to facilitate ease of loading under the varied conditions to be expected in mines and quarries, these sizes being 1½ by 6½, 1¼ by 6½, 1⅛ by 6½, 1¼ by 16½, and 1⅛ by 16½ inches. The cartridges were made by rolling an ordinary paper towel over a piece of glass tubing, folding up one end, and then filling with combustible material. Two compositions designed to have oxygen enough for complete combustion at the end of 10 minutes were chosen because all of the materials were at hand and were easily mixed; furthermore, they would be easily obtainable anywhere. Cartridge 23A10 was composed of pure, fine wood pulp, and cartridge 51A10 consisted of 16.7 per cent coal dust, 50 per cent wood pulp, and 33.3 per cent diatomaceous earth. The

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

A. BLOCK BEFORE FIRING.



B. BLOCK AT THE MOMENT OF FIRING.

C. BENCH AT THE MOMENT OF FIRING.

TEST OF LIQUID-OXYGEN EXPLOSIVES AT WARD'S QUARRY, PITTSBURGH, PA,

Generated on 2024-09-29 23:36 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

table below shows the approximate weights, with and without oxygen, of the different sizes of cartridges:

Weight of cartridges used.

Size.	Weight of cartridge 23A10.		Weight of cartridge 51A10.	
	Without (grams).	With O_2 (grams).	Without (grams).	With O_2 (grams).
1½ by 6½	65	153	88	184
1¼ by 6½	50	117	80	167
1⅛ by 6½	45	106	.....	.....
1½ by 16½	135	318	175	366
1⅛ by 16½	95	224	.....	.....

The usual procedure was to dip the cartridges into the liquid oxygen until they sank. The detonators, always No. 6 electric, were placed within the cartridge before dipping.

After the cartridges were put in the holes, they were usually stemmed with clay, either loose or made up in dummy cartridges. Except in very shallow holes, a "needle rod" (a brass tube, one-eighth inch internal diameter) was run into the cartridge while stemming was in progress, and was withdrawn before the shot was fired, as described in the 1917 tests. This was to allow for the escape of the evaporated oxygen which otherwise might blow out the stemming.

FIELD TEST NO. 1, NO. 2 LEFT BUTT, EXPERIMENTAL MINE, BRUCETON, PA.

Purpose of test.—The object of the shot was to blow down coal at the face of the entry.

Conditions of test.—The entry face was about 9½ feet wide by 7 feet high, and the coal had been undercut with a compressed-air punching machine. The "tight" shot had already been fired at the right rib with permissible explosive. The drill hole, which was 4 feet 10 inches deep and 1¾ inches diameter, sloped upward and outward. The entry was quite damp. There were 22 inches of "draw slate" above the coal.

Charge.—One 1½ by 6½ inch cartridge of mixture 51A10 was dipped, then loaded into the hole. The stemming, dummy clay cartridges, was inserted until the hole was filled. A needle rod was used. A blasting machine fired the cartridge 9½ minutes after dipping.

Results of blast.—The face of the entry was well squared up, but the coal lumps were too small, indicating that the hole had been overloaded. Some of the coal was thrown 18 feet from the face. The observers were stationed in a cut through about 40 feet from

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

the face. Considerable illumination was visible to them when the shot was fired. The flame apparently lasted several seconds.

Conclusions.—This one shot seems to indicate that a cartridge containing coal dust is too brisant for coal; also that it gives too much flame for safety in a coal mine.

FIELD TEST NO. 2, NO. 1 LEFT BUTT, EXPERIMENTAL MINE, BRUCETON, PA.

Purpose of test.—To blow down coal at the face of the entry.

Conditions of test.—The entry at the face was about 9½ feet wide and 9 feet high. There were 4 feet of draw slate above the coal. As in test No. 1, the coal had been undercut with a punching machine operated by compressed air. The drill hole near the right rib, which was to be used for the "tight" shot, was 3 feet 2 inches deep.

Charge.—Three 1½ by 6½ inch cartridges, No. 51A10 mixture, were employed. The detonator was placed in the outer end of the second cartridge. The hole was stemmed with dummy clay cartridges for its full depth. A needle rod was used. The shot was fired 6½ minutes after dipping the first cartridge.

Results of blast.—About a ton of coal was loosened, but not broken down completely. To the observers standing in a cut through it was apparent that there was a great deal of flame. Upon approaching the face immediately after the shot, flames were seen to be issuing from the loosened coal, and there were a number of intermittent, dull, weak explosions. These could have been caused by pieces of undetonated cartridge, but were more likely brought about by the union of uncombined oxygen with coal dust or gas formed by the blast.

Conclusions.—As in the previous case, it was apparent that the cartridge containing coal dust gave too much flame for safety in a coal mine.

FIELD TEST NO. 3, NO. 1 LEFT BUTT, EXPERIMENTAL MINE, BRUCETON, PA.

Purpose of test.—To blow down coal at the face of the entry.

Conditions of test.—The conditions at the face of the entry were those existing immediately after firing the "tight" shot, test No. 2. The coal had not been brought down completely by this shot, and on the whole conditions were not favorable for a successful butt shot. The drill hole, in this case, was 4 feet deep.

The charge.—Two 1½ by 6½ inch cartridges, No. 23A10 mixture, were used. The detonator was placed in the outer end of the first cartridge. The hole was stemmed to the top with dummy clay cartridges. A needle rod was employed. The charge was fired 7 minutes after dipping the first cartridge.

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Results of blast.—The coal was thrown down in large lumps. It broke clear over to the right rib. There was little flame.

Conclusions.—The pure wood-pulp cartridge apparently is more satisfactory in this case than a coal-dust cartridge would have been. The lumps were larger and there was no after flame.

FIELD TEST NO. 4, NO. 6 ROOM, EXPERIMENTAL MINE, BRUCETON, PA.

Purpose of test.—To blow down the coal at the face of the room.

Conditions of test.—The room at the face was 20 feet wide. The total height was 7 feet, there being 7 inches of "draw slate" above the coal. The tight shot on the right rib had been fired with permissible explosive, leaving a hanging block of coal 6½ feet wide on the left rib. As was customary, the coal had been undercut with a compressed-air punching machine. The drill hole near the left rib was 4 feet deep (see Fig. 14).

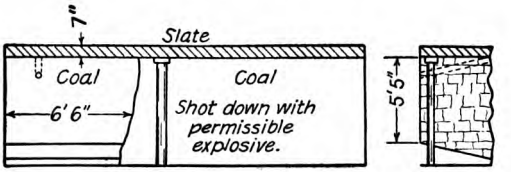


FIGURE 14.—Conditions of field test No. 4, room 6, experimental mine.

Charge.—One 1¼ by 6½ inch No. 23A10 cartridge was loaded into the hole. The detonator was placed in the outer end, and the hole completely stemmed with dummy clay cartridges. A needle rod was used.

Results of blast.—The coal was completely thrown down; the pieces were large; there was practically no flame.

Conclusions.—As in the preceding test, these results show that wood pulp seems a satisfactory material for blasting coal in non-gaseous and wet mines.

FIELD TEST NO. 5, NO. 2 RIGHT BUTT, NEW ENGLAND SECTION, PITTSBURGH TERMINAL R. R. & COAL CO., MINE NO. 7, PITTSBURGH BED.

Purpose of test.—To blow down the coal at the face of No. 2 butt, New England section, mine No. 7.

Conditions of test.—The face of the entry was 8 feet 8 inches high; the coal had been undercut by an electric machine. Two holes had been drilled near the rib on each side about 4 feet 2 inches from the floor. The right hole was loaded first.

Charge.—The charge was made of four 1¼ by 6½ inch No. 23A10 cartridges. The detonator was placed in the inner end of the third cartridge, put in the hole, and the hole was stemmed completely. The shot was fired eight minutes after dipping the first cartridge.

Results of shot.—The coal was not blown down, only a few cracks appearing in the coal below the hole. The hole was probably underloaded.

Generated on 2024-09-29 23:28 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Remarks.—The coal at this point was near a fault and unusually thick, the average height of the coal in the mine being 6 feet 8 inches. The miners claimed that it was unusually hard to shoot, and that it sometimes took three shots to blow down the coal at the face of an entry.

FIELD TEST NO. 6, NO. 2 RIGHT BUTT, NEW ENGLAND SECTION 1, PITTSBURGH TERMINAL R. R. & COAL CO., MINE NO. 7, PITTSBURGH BED.

Purpose of test.—To blow down the coal at the face of No. 2 butt, New England section, Mine No. 7.

Conditions of test.—Face and entry same as left after test 5, practically a tight shot.

Loading.—Five 1¼ by 6½ inch No. 23A10 cartridges were used. The detonator was placed in the outer end of the third cartridge, loaded, and the shot was fired seven minutes after dipping the first cartridge.

Results of shot.—The coal was broken down below but not above the hole. The coal was not scattered, merely set down.

Conclusions.—The shot could be classed as fair.

FIELD TEST NO. 7, FACE ENTRY NEW ENGLAND SECTION, PITTSBURGH TERMINAL R. R. & COAL CO., MINE NO. 7, PITTSBURGH BED.

Purpose of test.—To blow down coal at a face entry.

Conditions of test.—The entry at the face was 8½ feet high and 11½ feet wide. The coal had been undercut 6 feet with an electric undercutting machine. Two holes 1¾ inches diameter and 6 feet deep had been driven near the rib (see Fig. 15). The hole near the right side was the one loaded.

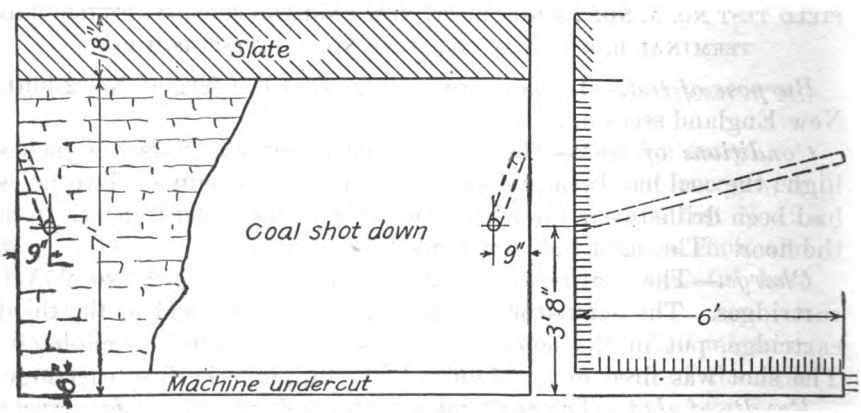


FIGURE 15.—Conditions of field test 7, Mine No. 7, Pittsburgh Terminal R. R. & Coal Co.

Charge.—Two 1¼ by 16 inch No. 51A10 cartridges and two 1¼ by 6½ inch No. 51A10 cartridges were used. The detonator was placed

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

in the inner end of the third cartridge. Both large cartridges were loaded first. The hole was stemmed its full depth with damp clay. No needle rod was used. The shot was fired 8 minutes after removing the first cartridge from the oxygen.

Results of test.—Simultaneously with the firing of the charge the end of the entry was filled with flame, which shot through the spaces between the lumps of coal thrown down, and there were a series of dull explosions in the rear. The flames lasted three or four minutes. The coal was said to be well shot down or scattered; the pieces were small enough to warrant the conclusion that the hole had been slightly overloaded.

About 9.9 tons were loaded out from the shot. Not enough oxygen remained to fire the second shot. The miners used 14 inches of black powder in this hole and got 3.85 tons of coal.

Conclusions and remarks.—Although a cartridge with coal dust as an active ingredient seems to bring down the coal well, it gives too much flame for safe use.

FIELD TESTS 8 TO 15, BLOCK-HOLE SHOTS IN LIMESTONE.

Eight tests, field tests 8 to 15, were made at Mine No. 1 of the Pittsburgh Limestone Co., West Winfield, Pa. The purpose of each test was to shatter a block of limestone. The conditions and the results are tabulated below:

TABLE 14.—*Field tests 8 to 15, at Mine No. 1, Pittsburgh Limestone Co., West Winfield, Pa.*

Test No.	Shape of block.	Dimensions (inches).	Weight (tons).	Size of drill hole (inches).	Usual amount of dynamite needed (stick).
8	Hexagonal	42 thick	6	1¾ by 30	1
9	Irregular	48 thick	8	1¾ by 33	
10	do	15 thick	¾	1¾ by 10	¼
11		72 by 32 by 45	6	1¾ by 30	
12	Cubical	42 on a side	5	1¾ by 21	
13	do	36 on a side	4	1¾ by 24	
14	do	36 on a side	5½	1¾ by 24	
15	do	36 on a side	4½	1¾ by 20	

Test No.	Oxygen cartridge used, amount, size, and mixture.	Stemming used.	Needle rod used.	Time from dipping cartridge to firing (minutes).	Result of shot.
8	One 1¼ by 6½ inch No. 23A10	Damp clay	Yes	6	Well broken, better than with dynamite.
9	One 1½ by 6½ inch No. 23A10		Yes	5	Well broken.
10	¼ of 1½ by 6½ inch No. 51A10	Damp clay	No	5	Broken into six pieces.
11	¾ of 1½ by 6½ inch No. 51A10	do	Yes	5	Well broken.
12	½ of 1½ by 6½ inch No. 51A10	Damp limestone	Yes	5	Do.
13	½ of 1½ by 6½ inch No. 51A10	do		5	Do.
14	¾ of 1½ by 6½ inch No. 51A10			5	Do.
15	½ of 1¼ by 6½ inch No. 23A10	Damp limestone		5	Do.

The 23A10 cartridge consists of pure wood pulp, and the 51A10 contains 16.7 per cent 200-mesh coal dust, 50 per cent wood pulp, and 33.3 per cent diatomaceous earth.

Generated on 2024-09-29 23:25 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

FIELD TEST NO. 16, ROOM 6, EXPERIMENTAL MINE.

Purpose of test.—To blow down coal in a mine room.

Conditions of test.—The No. 6 room of the experimental mine is 20 feet wide, the coal is 5 feet 3 inches high, and is covered with 22 feet of slate. The coal had been undercut with a punching machine to a depth of about 5 feet; the cut was 18 inches high in front and 6 inches at the back. Holes had been drilled the depth of the cut near each rib directly underneath the slate. The right hole was loaded first.

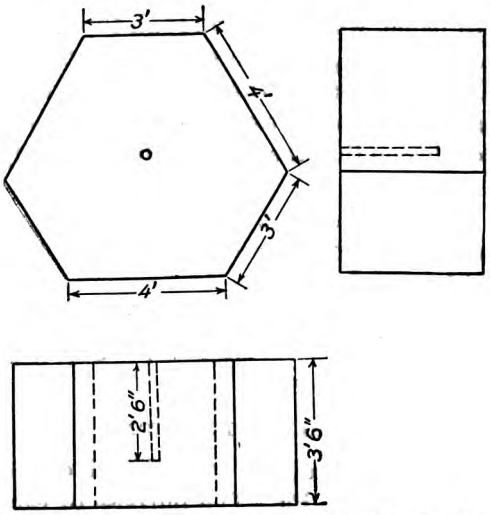


FIGURE 16.—Conditions of field test No. 8, Mine No. 1, Pittsburgh Limestone Co., West Winfield, Pa.

Loading.—One large 1¼ by 16 inch, and one small 1¼ by 6½ inch No. 23A10 cartridges (pure wood pulp) were used. The hole was stemmed completely by use of a needle rod and dummy clay cartridges. The shot was fired 8 minutes after dipping the first cartridge.

Results of shot.—About 6 tons of well-broken coal was brought down. Possibly the hole was slightly overloaded.

FIELD TEST NO. 17, ROOM 6, EXPERIMENTAL MINE.

Purpose of test.—To blow down coal in a mine room.

Conditions of test.—The condition of the room was that existing after test No. 16.

Loading.—One large 1¼ by 16 inch No. 23A10 cartridge (pure wood pulp) was used. The hole was stemmed to the top with dummy clay cartridges. A needle rod was used. The time of firing was 6½ minutes after dipping the cartridge.

Results of shot.—The remainder of the coal was brought down in huge lumps, excepting a bench about 2½ feet deep, or high, which clung to the slate and would drop when the broken coal was removed.

FIELD TEST NO. 18, MINE NO. 7, NEW ENGLAND SECTION, PITTSBURGH TERMINAL R. R. & COAL CO., LARGE, PA.

Purpose of test.—To blast up shaly fire-clay bottom to aid in grading main haulageway.

Generated on 2024-09-29 23:30 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Condition of test.—The bottom at this point was being cut down to a depth of 54 inches. A 6-foot hole had been drilled near the bottom of the wall fired by previous blasts.

Loading.—The hole was loaded with three 6½ by 1¼ inch No. 23A10 (pure wood pulp) cartridges. The No. 6 electric detonator was in the outer end of the second cartridge. The hole was stemmed with loose damp clay. The charge was fired 8 minutes after dipping the last cartridge.

Results.—There was no explosion. It was thought that the detonator had failed, but withdrawal of the charge showed that the detonator had exploded without deteriorating or igniting the charge. Analysis showed the oxygen content to be 97 per cent. The cartridge may have been slightly damp, but the tests mentioned on page 60 seem to indicate that dampness does not prevent detonation. The explanation of the misfire must lie in the tendency of wood pulp to render liquid-oxygen explosives insensitive.

FIELD TEST NO. 19, MINE NO. 7, NEW ENGLAND SECTION, PITTSBURGH TERMINAL R. R. & COAL CO., LARGE, PA.

Purpose of test.—To assist in blasting up a shaly fire-clay bottom for grading the main haulageway.

Condition of test.—A 6-foot hole inclined 20° from the horizontal had been drilled from the surface of the floor; it contained some water.

Loading.—Three 1¾ by 6½ inch No. 23A10 cartridges (pure wood pulp) were used. The No. 6 electric detonator was placed in the outer end of the second cartridge. The water in the hole could be heard bubbling as the oxygen in the cartridges escaped. The hole was stemmed to the top as customary.

Results.—The detonator was heard to explode but the cartridges did not ignite or detonate. (See test 18.) Here, as in test No. 18, the explanation of the misfire must lie in the tendency of wood pulp to render liquid-oxygen explosives, of which it is a constituent, insensitive. These results, taken in connection with the secondary minor detonations following the main detonation in field tests 2 and 7 and with the misfires obtained in physical tests, indicate that materials such as wood pulp and coal dust are unsuitable for use as the main combustible constituent of cartridges of liquid-oxygen explosives, unless enough sensitizing material has been used, as indicated in Table 12.

Generated on 2024-09-29 23:30 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

FIELD TEST NO. 20, MAIN HAULAGE ROAD, NEW ENGLAND SECTION, MINE NO. 7, PITTSBURGH TERMINAL R. R. & COAL CO.

Purpose of test.—To assist in blasting up shaly fire-clay bottom for grading.

Condition of test.—The entry at this point was 11 feet wide and 5 feet high. The floor inby the point of operation had been blasted with dynamite to a depth of 4½ feet. The result was that there was a face of shale the width of the entry, or 4½ thick (as shown in Fig. 17). The 5-foot drill-hole had been driven near the bottom of the wall near each rib. The left-hand hole was loaded first.

Loading.—Three 1⅛ by 16½ inch. No. 23A10 (pure wood pulp)

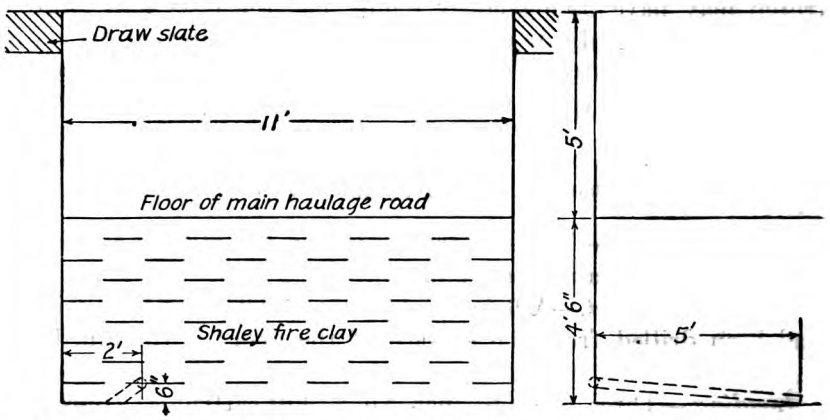


FIGURE 17.—Condition of field test No. 20, Mine No. 7, Pittsburgh Terminal R. R. & Coal Co.

cartridges were used. After the misfires of tests 18 and 19, two detonators were used. One was put in the outer end of the first cartridge, the other at the inner end of the third and last cartridge placed. The hole was stemmed with damp clay, and a needle rod was used. The charge was fired with a dry battery 8½ minutes after the dipping of the first cartridge. There was some smoke that had the odor of burning brush.

Results of the blast.—The shale was found to be well broken up for about 5 feet over and back. The miners expressed the opinion that it was broken better than it would have been had 40 per cent dynamite been used.

FIELD TEST NO. 21, MAIN HAULAGE ROAD, NEW ENGLAND SECTION, MINE NO. 7, PITTSBURG TERMINAL R. R. & COAL CO.

Purpose of test.—To blow up shaly fire-clay bottom for grading.

Condition of test.—The same as for test No. 20, except that the shale on the left side of the entry had been shattered by that test. This shot was in the right-hand side.

Generated on 2024-09-29 23:33 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Loading.—Four small 1¼ by 6½ inch No. 23A10 (pure wood pulp) cartridges were used, and two detonators were employed, one in the outer end of the first and the other in the outer end of the third cartridge inserted. The hole was stemmed with damp clay and a needle rod was used. The shot misfired with the battery, but was fired with the trolley wire and rail circuit 7½ minutes after dipping the first cartridge.

Results.—The stone was broken into small pieces near the hole. Fractures extended from the rib to the former blast; the pieces were mostly larger than in test 20, and though the shot was good, it was not quite as good as the one in that test.

FIELD TEST NO. 22, MAIN HAULAGE ROAD, NEW ENGLAND SECTION, MINE NO. 7, PITTSBURGH TERMINAL R. R. & COAL CO.

Purposes of test.—To blow up shaly fire-clay floor of haulage road for grading.

Condition of test.—A large pit about 2 feet deep had been blasted in the floor. In the face of the wall thus formed on the inner side of the hole, 4 inches from the bottom and 3 feet from the rib, a 1¾-inch drill hole 33 inches long had been drilled at 20° with the horizontal.

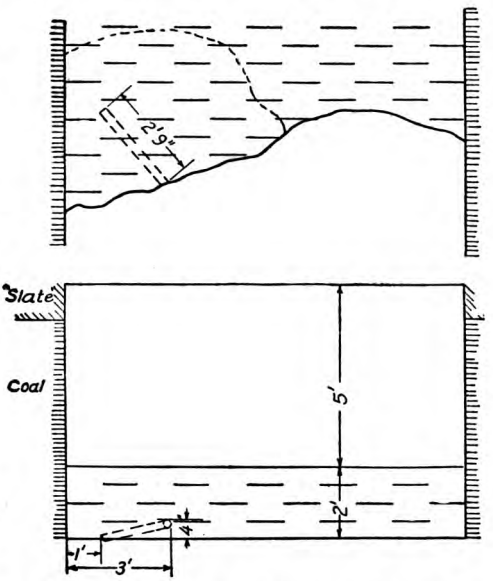


FIGURE 18.—Conditions of field test No. 22, Mine No. 7, Pittsburgh Terminal R. R. & Coal Co.

Loading.—Two small 1⅛ by 6½ inch No. 23A10 cartridges were used; one detonator was placed at the outer end of the first cartridge loaded. The hole was stemmed to the top with damp clay. No needle rod was used. The shot was fired by means of the trolley wire and rail circuit about 4 minutes after the first cartridge was dipped.

Results of shot.—The shale was broken as shown by the dotted line in Figure 18. The miners expressed the opinion that the results compared favorably with 40 per cent dynamite.

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

FIELD TEST NO. 23, PITTSBURGH LIMESTONE QUARRY, HILLSVILLE, PA., BENCH SHOT, EXPLOSIVE 23A10.

Place of test.—The limestone at the quarry lies in two beds a few inches apart. The top bed is 16 feet thick, the bottom 4 feet. The overburden of earth, 12 to 14 feet thick, is removed by steam shovels. Four 1¾-inch holes were drilled 6 feet deep and 8 feet back from the face of the quarry, but only one could be loaded, as there was not enough liquid oxygen for more. Each hole required the equivalent of eight sticks of dynamite.

Loading.—Four 1¾ by 15 inch sticks of No. 23A10 (pure wood pulp) were used. The hole was stemmed to the top with damp drillings. The cartridges were fired 8 minutes after dipping the first cartridge. The final cartridge loaded had to be dipped hurriedly, and possibly was not completely saturated; to make saturation certain, about a pint of the oxygen was poured into the hole before the stemming was placed.

Results of shot.—Small pieces of stone were blown 60 feet into the air. One large piece, 15 by 6 by 4 feet, was dislodged from the face of the cliff.

The quarrymen said that they seldom fired a single dynamite shot, so could not tell just what to expect, but the hole was broken out more than it would have been with dynamite, and they considered that good execution had been done.

DANGERS INCIDENT TO USE OF LIQUID-OXYGEN EXPLOSIVES.

SENSITIVENESS TO FLAME.

Because of the doubts as to the safety of liquid-oxygen explosives in mines where open lights are carried, especially in view of the enrichment of the mine air by the evaporating oxygen, several tests were made to determine with what ease these explosives would ignite, and whether an explosion would occur in consequence. Several 38-mm. cartridges, 20 cm. long, of mixture No. 14 were impregnated with liquid oxygen and slipped into corrugated pasteboard insulators. These cartridges were laid on the ground and a lighted miner's lamp brought so near that its flame was less than an inch from the end of the cartridge from which the oxygen gas was issuing. No ignition occurred. The cartridge did not ignite until the flame was played upon its end; then it burned with an intensely bright flame for a few moments. There seemed to be a slight explosion, which was only the rupture of the insulation by the sudden evaporation of oxygen under the heat. No detonation occurred. Doubtless if a detonator or a blasting cap were contained in the end ignited the explosive would be more liable to detonate; but, on the

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

other hand, the cartridge would be ruptured and its explosive ingredient scattered so soon after the ignition that if the detonator were imbedded an appreciable distance in the cartridge the heat would not reach it before the cartridge was ruptured and scattered; hence any detonation of explosive would be that of a very small charge.

IMPURITIES IN EXPLOSIVE INGREDIENTS.

Explosions have happened in the use of liquid-oxygen containers made of metal and containing charcoal between the walls.[10] Sometimes when the walls of the containers were ruptured and the liquid oxygen gained access to the charcoal, explosions occurred; at other times no explosions resulted. It was found that the charcoal in the faulty vessels contained zinc and iron, and that 3.5 per cent of the iron, as oxide in the charcoal, caused an explosion on contact with liquid oxygen; 2 to 3 per cent gave rise to a violent reaction, but less than 2 per cent produced no deleterious effect. The iron oxide seems to act catalytically as an oxygen carrier, and 0.1 gram of the highly porous charcoal containing the designated amount of iron oxide proved enough to cause an explosion.

It is obvious, therefore, that care should be taken that any charcoal to be used, either as an ingredient of liquid-oxygen explosives or for preserving the vacuum in metallic containers, contains less than 2 per cent of iron oxide.

IMPROPER CHARGING CONDITIONS.

According to Wöhler, premature explosions of blasting cartridges containing soot or sawdust and liquid oxygen have occurred during charging through the liquid oxygen coming in contact with combustible material that had been heated by the process of tamping. It would seem, then, that care should be taken to use stemming free from combustible material.

ACTION OF LOW TEMPERATURE ON MERCURY FULMINATE COMPOSITION.

Before beginning the work on liquid-oxygen explosives, the question arose as to whether cooling the electric detonator to the temperature of liquid air would involve any dangers or would reduce the efficiency of the detonator.

The tests reported by Kling and Florentine (12) in 1913, in which mercury fulminate compositions were subjected to the temperature of liquid air, showed that the fulminate was but slightly, if any,

[10] Wöhler, Lothar, Chem. Ztg., Oct. 5, 1918; Engineering, vol. 106, p. 687; Cf. Chem. Abstracts, vol. 13, 1919, p. 791.

Generated on 2024-09-29 23:38 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

less sensitive at these extremely low temperatures than at normal temperatures. Tests of liquid-oxygen explosives herein reported have not shown electric detonators to be less efficient at very low temperatures. In the Trauzl lead-block tests, particularly, bits of the copper capsule of the electric detonator, recovered after shots in which no explosion or a slight explosion of the explosive occurred, were shattered to the same degree as by similar shots fired at normal temperatures.

Generated on 2024-09-29 23:33 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

SELECTED BIBLIOGRAPHY ON LIQUID AIR.

1. LINDE, CARL, Zur Geschichte der Maschinen für die Herstellung flüssigen Luft: Ber. Deut. chem. Gesell., Jahrg. 32, 1899, pp. 925–927.

2. OSTWALD, WILHELM, Pariser Brief; Ztschr. angew. Chem., Jahrg. 20, part 2, 1907, pp. 1589–1591.

3. TELLIER, CHARLES, L'Antonomique, Paris, 1867.

4. CLAUDE, GEORGES, Sur la liquéfaction de l'air par détente avec travail extérieur: Compt. rend., t. 141, 1905, pp. 762–764.

5. ENGINEERING, The separation of oxygen from liquid air; vol. 85, June 5, 1908, pp. 761–762.

6. CLAUDE, EUGENE, Improvements in and apparatus for the manufacture of liquid air, British patent 12965, May 23, 1895.

7. HAMPSON, W., Improvements relating to the progressive refrigerating of gases, British patent 10165, May 23, 1895.

8. LINDE, CARL, Verfahren zur Verflüssigung atmosphärischer Luft oder anderer Gase, German patent 88824, June 5, 1895.

9. ———, Process and apparatus for liquefying gases or gaseous mixtures and for producing cold, more particularly applicable for separating oxygen from atmospheric air, English patent 12528, June 28, 1895.

10. SIEDER, L., Oxyliquit: Ztschr. ges. Schiess u. Sprengs., Jahrg. 1, 1906, p. 87.

11. DIEDERICHS, H., Die Erzeugung und Verwendung flüssiger Luft zu Sprengwecken: Stahl u. Eisen, Jahrg. 35, Nov. 11, 1915, pp. 1145–1151; Nov. 18, 1915, pp. 1177–1181.

12. KLING, ANDRÉ, and FLORENTIN, D., Action des basses températures sur les explosifs: Compt. rend., t. 156, 1913, pp. 694–696.

13. ABEL, C. D., New explosive compound, British patent 18929, August 16, 1897.

14. KOWASTCH, AMBROSIUS, and BALDUS, C. A., Verfahren zum Besetzen von Bohrlöckern, German patent 244035, Oct. 15, 1909.

15. SIMONIS, OTTO, Improvements in and connected with the method of and means for blasting or exploding by liquid air, oxygen, or like suitable liquefied gas or medium of low temperature, British patent 24137, Oct. 24, 1913.

16. DEWAR, JAMES, An improved method of absorbing gases and the method thereof for the production of high vacua and the separation of gases, British patent 13638, June 16, 1904.

17. OSTERGREN, O. P., Improvements in receptacles for holding and storing liquids, more particularly liquid air and other liquefied gases, British patent 10883, May 24, 1899.

18. DYMOND, G. C., Improved means for conserving and for dissipating liquid gases, British patent 6039, Mar. 20, 1899.

19. First rectification.

20. EUCKEN, A., [Heats of evaporation, fusion, and transformation of liquid oxygen and nitrogen]: Verhandl. Deut. physik. Ges., Jahrg. 18, 1916, pp. 4–17.

21. MATHIAS, E., Sur la chaleur de vaporization des gas liquéfiés: Compt. rend., t. 140, 1905, pp. 1174–1176.

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

22. WITT, GUSTAV, [Heat of vaporization of liquid air]: Arkiv. Mat. Astron. Physik, Jahrg. 7, No. 32, pp. 1–13.

23. BALY, E. C. C., Distillation of liquid air, and the composition of the gaseous and liquid phases: Phil. Mag., vol. 49, 1900, pp. 517–529.

24. DEWAR, JAMES, Studies on charcoal and liquid air: Chem. News, vol. 97, Jan. 3, 1908, pp. 4–8; Jan. 10, 1908, pp. 16–19.

25. CLAUDE, GEORGES, [Liquid air, oxygen, and nitrogen].

26. LINDE, CARL, Machine pour l' obtention des basses températures pour la liquéfaction des gaz et la separation mecanique des mélanges gazeux: Génie civil, t. 31, 1897, pp. 51–55.

27. HAMPSON, W., Self-intensive refrigeration of gases, liquid air and oxygen: Jour. Soc. Chem. Ind., vol. 17, 1898, pp. 411–421.

28. CLAUDE, GEORGES, Perfectionnements apportés aux procédés d'extraction de l'oxygène de l'air par voie de liquefaction, French patent 299051, Apr. 9, 1900.

29. LINDE, CARL, Verfahren und Apparat zur Herstellung von Sauerstoff von beliebiger Reinheit, German patent 173620, Feb. 27, 1902.

30. WOOD, W. O., and KNUDSEN, HANS, Method of obtaining disruptive or explosive effects, United States patent 845604, Feb. 26, 1907.

31. RICE, G. S., Development of liquid-oxygen explosives during the war: Tech. Paper 243, Bureau of Mines, 1920, 46 pp.

32. ———, Data concerning the use of liquid-oxygen explosives in Germany: Serial No. 2163, Bureau of Mines, Sept., 1920.

33. DEWAR, JAMES, Liquid oxygen and the war: Jour. Soc. Chem. Ind., vol. 38, Jan. 31, 1919, pp. 23R–24R.

34. COMPRESSED AIR MAGAZINE, Liquid-oxygen explosives: January, 1919, pp 8996–8999.

35. WOLF, A. G., Liquid oxygen as an explosive: Eng. and Min. Jour., vol. 109, Feb. 14, 1920, p. 438.

36. LISSE, —, Blasting with liquid air: Min. and Sci. Press, vol. 122, June 18, 1921, pp. 843–844.

37. SKERRETT, R. G., Potentialities of liquid-oxygen explosives: Compressed Air Mag., June, 1921, pp. 10103–10107.

38. HOLST, G., Vapor pressures of oxygen and nitrogen: Proc. Acad. Wetenschappen, Jahrg. 18, 1916, pp. 829–839.

39. ERDMANN, ERNST, Über die Zusammensetzung und Temperatur der flüssiger Luft: Ber. Deut. chem. Gesell., Jahrg. 37, 1904, pp. 1193–1196.

40. PIUTTI, ARNOLDO, Sopra un miscuglio esplosivo di fosforo ed aria liquida: Rend. Atti Real. Accad. Lincei, vol. 24, 1915, part 2, pp. 252–253.

41. LODENBURG, A., and KRÜGEL, C., Über die specifischen Gewichte der flüssigen Luft und einiger anderer, flüssiger Gase: Ber. Deut. chem. Gesell., Jahrg. 32, 1899, pp. 46–49.

42. VERSHAFFELT, J. E., and NICAISE, C., The viscosity of liquid air: Proc. Akad. Wëtenschappen, Jahrg. 18, 1916, pp. 840–856, 1039–1045, 1659–1675.

43. BROT, HENRI, [Mathematical theory of liquid air machines and of the expansion of gases]; Bull. Soc. Encour. Ind. Nat., t. 121, July–August, 1915, pp. 16–50.

44. CAUBET, F., Sur la liquéfaction des mélanges gazeux; les isothermes d'un mélange: Compt. rend., t. 131, 1900, pp. 1200–1202; Sur la liquéfaction des mélanges gazeux; variation des concentrations des duex phases coexistantes liquide et vapeur le long des isothermes: Compt. rend., t. 132, 1901, pp. 128–131.

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

45. ERDMANN, ERNST, and BEDFORD, FRED, Über Reindarstellung und Eigenschaften des flüssigen Sauerstoffs: Ber. Deut. chem. Gesell., Jahrg. 37, 1904, pp. 1184–1193.

46. GROUSINOFF, A. S., [Change in the composition of liquid air on evaporation, independent of the rate of evaporation]: Jour. Russ. Phys. Chem. Soc., vol. 32, part 2, 1900, p. 107.

47. CLAUDE, GEORGES, Sur l'absorption des gaz par le charbon aux basses températures: Compt. rend., t. 158, 1914, pp. 861–864.

48. SCHROTER, M., Liquid air and oxygen, their commercial manufacture; discussion of the Linde air machine: Engineer, Oct. 4, 1895, p. 325.

49. D'ARSONVAL, ARSENE, L'air liquide: Ann. chim. phys., t. 26, ser. 7, August, 1902, pp. 433–460.

50. JAUBERT, G. F., History of liquid air: Rev. gen. chim., t. 17, pp. 77, 96.

51. OLSZEWSKI, KARL, Przyrzady do skroplenia powietrza i wodoru [Apparatus for the liquefaction of air and hydrogen]: Bull. Acad. Sci. Cracow, ser. 3a, part 2, 1902, pp. 457–470.

52. CLAUDE, GEORGES, Sur l'extraction de l'oxygène par la liquéfaction partielle de l'air avec retour en arrière: Compt. rend., t. 137, 1903, pp. 783–786.

53. HUDSON, C. S., and GARLAND, C. M., Test of a liquid air plant: Univ. of Ill. Bull. 21, March, 1908, 20 pp.

54. GARVER, M. M., Theoretical efficiency of the Linde process of liquefying air: Jour. Franklin Inst., vol. 177, 1914, pp. 305–314.

55. HILDEBRANDT, GOTTHOLDT, Liquid air separation, Canadian patent 145993, Feb. 18, 1913.

56. ———, Process of separating liquid air into its constituents, United States patent 1119158, Dec. 1, 1914.

57. CLAUDE, GEORGES, Process for separation of the constituents of gaseous mixtures, United States patent 1068219, July 22, 1913.

58. NEUMANN, ADOLF, Vorrichtung zur Herstellung und Scheidung flüssiger Luft, German patent 281518, March 2, 1913.

59. SIMON, LEO, Procédé pour la fabrication d'oxygène par distillation fractionée d'air liquide, French patent 466685, Dec. 27, 1913.

60. L'Air Liquide (Société Anonyme pour l'Étude et l'Exploitation des Procédés George Claude à Paris), Fremgangsmaate for fremstilling og rektifikation av flytende luft [Process for producing and rectifying liquid air], Norwegian patent 27168, Aug. 7, 1916.

61. ———, Lederdichtung für Maschinenteile, welche in tiefen Temperaturen arbeiten, German patent 273276, Oct. 17, 1913.

62. CLAUDE, GEORGES, Perfectionnements à la fabrication de l'air liquide, French patent 296211, Jan. 16, 1900.

63. ———, Perfectionnements apportés à la fabrication des gaz liquéfiés, French patent 322107, June 16, 1902.

64. ———, Liquefaction of air and its separation into its constituents, United States patent 981748, Jan. 17, 1911.

65. ———, Process for the separation of oxygen and nitrogen from liquid air, United States patent 950436, Feb. 22, 1910.

66. GESSELLSCHAFT FÜR LINDES EISMASCHINEN, Verfahren zur Zerlegung von Luft oder andern Gasgemischen, Swiss patent 72421, May 16, 1916.

67. MORRISON, A. C., Process of separating mixed liquefied gases, United States patent 1056043, Mar. 18, 1913.

68. SOLVAY, ERNEST, New or improved apparatus for and process for producing, applying, and keeping up extreme temperatures, British patent 13466, Nov. 6, 1885.

Generated on 2024-09-29 23:32 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

69. THRUPP, E. C., Improvements in apparatus for liquefying air and separating oxygen therefrom, British patent 18913, Oct. 23, 1900; United States patent 743349, 1903.

70. PLACE, J. F., Apparatus for liquefying and separating atmospheric air, United States patent 1123588, Jan. 5, 1915; Air liquefier and separator, United States patent 1146020, July 13, 1915; Art or process of liquefying air and separating the same into oxygen and nitrogen, United States patent 1157959, Oct. 26, 1915.

The following patents have been granted for liquid-oxygen processes:

UNITED STATES.

BOBRICK, G. A., Process for the liquefaction of gases and separation of air into commercial oxygen and nitrogen, United States patent 924136, June 8, 1909.

DUMARS, HORACE, Plant for the handling and utilization of liquid air and the like, United States patent 954268, Apr. 5, 1910.

GALLAUDET, E. F., Art of liquefying gas and separating its elements, United States patent 981755, Jan. 17, 1911.

HAZARD-FLAMAND, MAURICE, Apparatus for dividing air into its elements by fractional distillation, United States patent 1201043, Oct. 10, 1916.

HOURLIER, PIERRE, Packing for machinery, United States patent 1179185, Apr. 11, 1916.

JÄNECKE, ERNST, Process of liquefying air and separating it into its elements, United States patent 1015800, Jan. 30, 1912.

LINDE, CARL, Process of producing low temperatures, the liquefaction of gases, and the separation of the constituents of gaseous mixtures, United States patent 727650, May 12, 1903.

MEWES, RUDOLF, Process of liquefying air and separating out oxygen, United States patent 980813, Jan. 3, 1911.

———, Apparatus for liquefying and separating gases, United States patent 1215957, Feb. 13, 1917.

PICTET, R. P., Apparatus for liquefying air and other gases, United States patent 830613, Sept. 11, 1906.

———, Process of separating gaseous mixtures into their constituents, United States patent 1119312, Dec. 1, 1914.

PLACE, J. F., Art or process of liquefying air or other gases and cooling by means thereof, United States patent 707633, Aug. 26, 1902.

———, Art or process of producing liquid air, United States patent 918468, Apr. 13, 1909.

DENMARK.

FILIPPO, HENDRIK, AND SCHOONENBERG, PANCRAS, Anordning ved Apparater til Fremstilling af Ilt af Luft, Danish patent 21369, July 11, 1916.

FRANCE.

ATMOSPHERIC OXYGEN AND POWER CO., Perfectionnements apportés aux appareils propres à liquéfier l'air et en séparer les éléments constitutifs gazeux, French patent 321860, June 6, 1902.

FILIPPO, HENDRIK, AND SCHOONENBERG, PANCRAS, Perfectionnements dans les appareils pour l'extraction de l'oxygène de l'air, French patent 480915, Feb. 10, 1916.

Generated on 2024-09-29 23:30 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

INDUSTRIEGAS GESELLSCHAFT FÜR SAUERSTOFF -UND STICKSTOFF -ANLAGEN, Procédé de préparation d'oxygène et d'azote au moyen de l'air liquide, French patent 446560, July 26, 1912.

SOCIÉTÉ ANONYME COMPAGNIE INTERNATIONALE DE L'OXYGÈNE, Procédé et dispositifs de séparation de l'air liquide, uniquement par distillation en oxygène et en azote, French patent 466315, Dec. 16, 1913.

GERMANY.

HECKER, B., Verahren und Vorrichtunger zur Zulegungflüssiger Gasgemische z. B. atmosphärische Luft, in ihre Bestandteile, German patent 204807, Mar. 5, 1908.

JÄNECKE, ERNST, Verfahren zum Absorbieren von Gasen oder Dämpfen mittels Holzkohle, German patent 169514, Apr. 26, 1905.

———, Verfahren und Vorrichtung zur Zerlegung flüssiger Luft in ihre Bestandteile, German patent 220270, Feb. 13, 1908.

———, Vorrichtung zur Trennung flüssiger Luft in ihre Bestandteile mittels eines Rektifikationskolonne mit Rückfluszkühler, German patent 246341, Nov. 12, 1910.

LÉVY, R. J., Verfahren zur Zerlegung von Luft in Stickstoff und Sauerstoff, German patent 191916, Mar. 27, 1903.

MEWES, RUDOLF, Luftverflüssigungsverfahren, German patent 209074, Oct. 26, 1905.

———, Verfahren und Vorrichtung zur Luftverflüssigung und Sauerstoff-Stickstoffgewinnung, German patent 222840, May 22, 1907.

———, Verfahren und Vorrichtung zur Verminderung von Wärmeverlusten in den Apparaten zur Luftverflüssigung und Gestrennung, German patent 230002, July 9, 1904.

———, Vakuumgefasz für flüssigte Gase, insbesondere für flüssige Luft und flüssigen Sauerstoff, German patent 292727, July 24, 1915.

STEIN, FRIEDRICH, VORRICHTUNG zum selbsttätigen Zurückführen der aus der Saugleitung von Kältemaschinen abgeschiedenen Flüssigkeit in den Verdampfer, German patent 174352, Sept. 13, 1904.

GREAT BRITAIN.

INDUSTRIEGAS GESELLSCHAFT FÜR SAUERSTOFF-UND STICKSTOFF-ANALAGEN, An proved process and apparatus for obtaining oxygen and nitrogen from liquefied air, British patent 17431, July 26, 1912.

LOCHMAN, WALTER, Continuous separating process for gas mixtures and apparatus therefor, British patent 100085, Feb. 10, 1916.

RUNGE, HANS, Process of separating air into oxygen and nitrogen, British patent 3420, Feb. 10, 1914.

NORWAY.

PICTET, R. P., Fremgagsmaate og anordning til av gasblandinger at utskille de forskjellige gaser, hvorav de bestaar, Norwegian patent 26769, Mar. 13, 1916.

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

INDEX.

A.

Page.

Absorbents, liquid-oxygen explosives— 17
standard cartridges, table of— 30–33
Absorption tests, description of— 17, 19
results of— 19, 22
Air, composition of— 9
first liquefaction of— 5
See also Liquid air.
Allison, V. C., work of— iii
Aluminum, complete combustion of, oxygen for, amount of— 28
deflection of ballistic pendulum by— 36
Aluminum sulphate mixtures, complete combustion of, time for— 23
composition of— 23
specific gravity of— 23
Anthracite mines, use of liquid oxygen in— 2
Asbestos, as insulator— 18, 34
comparison with other wrappers— 61

B.

Ballistic-pendulum tests, discussion of— 44
No. 8 detonator— 59
results of— 4, 36, 37–43
Baly's curves. *See* Nitrogen-oxygen mixtures— x
Bench shots. *See* Pittsburgh, Pa., quarry at.
Bibliography— 81
Bituminous coal dust, absorption and evaporation rates of— 19, 22
deflection of ballistic pendulum by— 36
insensitiveness of— 44, 46, 49
Bituminous coal-dust mixtures, complete combustion of, time for— 23
composition of— 23
specific gravity of— 23
Black blasting powder, length and duration of flame of— 51
Blotting paper, comparison with other wrappers— 61
Block-hole shots. *See* Pittsburgh, Pa., quarry at.
Bond paper, comparison with other wrappers— 61
Bruceton, Pa. *See* Experimental mine.

Page.

Bureau of Mines, dipping container of, description of— 14
figure showing— 14
views of— 14
experiments of, results of— 3–4
work on liquid-oxygen explosives by— iii

C.

Calletet, —, method of liquefying oxygen of— 5
Cannon, detonation tests with— 59
Carbon monoxide, first liquefaction of— 5
Cartridges, absorption and evaporation tests with, 1-inch— 17–19
2¼ inch— 19–22
charge, separation of, prevention of— 49
cross section of— 20
diameter, relation to life of— 4, 60
evaporation curves for, 1-inch— 18
2¼ inch— 22
preparation of, views of— 66
sizes and weights used in field tests— 68, 69
standard, absorbents for, table of— 30–33
absorption and evaporation tests of, results of— 26
ballistic-pendum tests of, discussion of— 44
results of— 37–43
detonation tests of, results of— 37, 47, 48
evaporation curves for— 26
evaporation rate of, comparison of— 36
specific gravity of— 37–43
strength, comparison with dynamite— 37–43, 44
unconfined, detonation tests of, results of— 45
percentage of hydrocarbon needed for— 45
unexploded, safety of— 4, 49
view of— 20
See also Formulae; Liquid-oxygen explosive; and ingredients named.
Cascade method, liquifying oxygen by— 5
Cellulose, complete combustion of, oxygen for, amount of— 28

Generated on 2024-09-29 23:27 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Page.

Chambering shot. *See* Morewood Extension.
Charcoal, complete combustion of, oxygen for, amount of 28
deflection of ballistic pendulum by 36
insensitiveness of 44, 46, 49
iron oxide in, danger from 79
See also Willow charcoal.
Charging, precautions for 79
Cheesecloth, absorption and evaporation, rates of 19, 22
Cheesecloth wrappers, use of 18, 19
Claude, Eugene, work cited 7
Claude, Georges, acknowledgement to 4
work cited 5, 7, 8, 13, 48
Coal dust. *See* Bituminous coal dust; Pittsburgh coal dust.
Coal mines, use of liquid-oxygen explosives in 2, 4, 59
Combustibles, in liquid-oxygen explosives 16
Combustion, complete, explosive mixtures, time for 23
Containers, description of 12–15
evaporation tests of, results of 25
curves showing 25
Cooling methods, liquid air 6
Corrugated pasteboard, as insulator 19, 24, 36, 48
Costs, discussion of 2
Cotton, absorption and evaporation rates of 19, 22, 26
Cotton mixtures, complete combustion of 23
composition of 23
specific gravity of 23
Crawford, F. S., work of iii
Crude oil, as absorbent 4
Crude oil mixtures, absorption and evaporation rates of 19, 22
complete combustion of, time for 23
composition of 23
specific gravity of 23

D.

Decomposition products, heat capacity 55, 56
Detonation rates, different explosives, comparison of 48
special tests, results of 48
Detonation tests, in cannon 59
unconfined cartridges, results 45
under water 59
with No. 8 detonator 59
Detonators, commercial, composition of 63
effect of liquid oxygen on 64
See also Electric detonator; German detonator; Liquid-oxygen detonator; Safety fuse.
Dewar, James, work cited 8, 14
Diameter. *See* Cartridges.

Page.

Diatomaceous earth, absorption and evaporation rates of 19, 22, 26
as absorbent 4
as combustible 17
effect of pressure on absorption by 62
evaporation; curves for 29–30
use recommended 50
wet, in explosive 23
Diatomaceous-earth mixtures, complete combustion of, time for 23
composition of 23
specific gravity of 23
Diederichs, H., work cited 8
Dipping containers, description of 14, 15
design of 4
figure showing 14
Dynamite, strength, comparison with liquid-oxygen explosives 37–43, 44
Dymond, G. C., work cited 13

E.

Electric detonator, No. 6 fulminate, detonation tests of, results of 47
use of 4
Equilibrium concentrations. *See* Nitrogen-oxygen mixtures.
Evaporation curves. *See* cartridges; Diatomaceous earth; Wood pulp.
Evaporation tests, description of 17, 19
results of 19, 22
Experimental mine, Bruceton, Pa., conditions of test No. 4 at, figure showing 71
field tests at 69–71, 74
Explosions, premature, danger of 78–80
Explosives, materials in 16
See also Black blasting powder; Liquid-oxygen explosive; Permissible explosive.

F.

Field tests, liquid oxygen explosives 65–78
Flame, sensitiveness of liquid oxygen explosives to 78
Flame temperatures, calculations of 54, 55
low, explosives with, formulae for 58
reduction of 56
Flame test, results of 51–52
figure showing 51
Flour, deflection of ballistic pendulum by 36
Formulae, liquid-oxygen explosive, composition of 23, 27
recommended 50
low-frame temperatures 58
reasons for not using 27, 28
See also Liquid-oxygen explosive mixtures.

Generated on 2024-09-29 23:31 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

	Page.
France, mines in, use of wood pulp in	51
use of liquid-oxygen explosives in	3
Fuse, effect of liquid oxygen on	65
Fuse. *See also* Safety fuse.	
G.	
Gallery tests, results of	53
Gases, liquefaction of, history of	5
Gas oil, complete combustion of, oxygen for, amount of	28
deflection of ballistic pendulum by	36
sensitiveness of	44
use recommended	50
Gaseous mines, use of liquid-oxygen explosives in	4, 51
German detonater, test of	60
Germany, use of liquid-oxygen explosives in	1, 3
use of portable plants in	3
use of shot-firing circuits in	3
Glass containers, use and disadvantages of	13
H.	
Hall, Clarence, Snelling, W. O., and Howell, S. P., work cited	58
Hampson, work cited	6
Hardened cartridges. *See* Paraffin cartridges.	
Hillsville, Pa., quarry at, field tests at	78
Howell, S. P., and Tiffany, J. E., work cited	33, 35, 60
Hydrocarbons, liquid, as absorbent	4
percentage needed for detonation	45
sensitiveness of	44, 46, 49
I.	
Impurities, dangers from	79
Influence tests, results of	60
Insulating material, for containers	15
Insulators. *See* Asbestos; Corrugated pasteboard; Paper; Wrappers.	
Iron mines, use of liquid oxygen in	2
Iron oxide, in charcoal, danger from	79
K	
Kowastch, A., and Baldus, C. A., work cited	8
Kraft paper, comparison with other wrappers	6
L.	
Lampblack, absorption and evaporation rates of	19, 22, 23
as combustible	17
Lampblack mixtures, complete combustion of, time for	23
composition of	23
specific gravity of	23
Large, Pa., field tests at	71–72, 74–77
field test no. 7, condition of, figure showing	73
Lead-block tests, small, results of	49
See also Trauzl tests.	
Leighton, Alan, work of	iii
Lentz, H. L., work of	iii
Limestone. *See* Hillsville; West Winfield.	
Linde, Carl, work cited	6, 7, 8
Liquid air, cooling, methods for	6–7
oxygen content of	11
percentage of oxygen recommended for	4
physical properties of	9
Liquid oxygen, analysis of	59
as oxidizing agent	16
boiling point of	7, 11
density at boiling point	11
evaporation from detonators, time for	64
from oxygen-nitrogen mixtures	12
physical properties of	12
production from air, history of	11
Liquid-oxygen cartridges. *See* Cartridges.	
Liquid-oxygen detonator, test of, results of	47
Liquid-oxygen explosive mixtures, complete combustion of, time for	23
No. 4, combustion of, products of	53
composition of	52
specific gravity of	23
Liquid-oxygen explosives, advantages of	1
amount used in Germany	3
comparative strength of	34
dangers from	78–80
disadvantages of	2
length and duration of flame of	51
materials in	16–17
See also Formulæ.	
sensitiveness of, material affecting	44
possible uses of	2
use of, history of	8
Loading period, duration of	3
M.	
Manganese sulphate mixtures, complete combustion of, time for	23
composition of	23
specific gravity of	23
Manila paper, as insulator	34
comparison with other wrappers	61
Mercury fulminate, effect of low temperature on	79
Metal containers, description and use	14–15
disadvantages of	13
Methane, first liquefaction of	5
Mines, use of liquid oxygen in	2, 51

Generated on 2024-09-29 23:29 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

	Page.
Moisture, effect on wood pulp cartridge	60
See also Water.	
Morewood Extension, Pittsburgh, Pa., tests at	65
views showing	67
N.	
Naphthalene, complete combustion of, oxygen for, amount of	28
deflection of ballistic pendulum by	36
sensitiveness of	44
Naphthalene mixtures, absorption and evaporation rates for	26
Newsprint paper, comparison with other wrappers	61
Nitrogen, boiling point of	11
density at boiling point	11
first liquefaction of	5
Nitrogen-oxygen mixtures, equilibrium concentrations of, table showing	11
curve showing	10
O.	
Oil. *See* Crude; Gas oil; Residuum oil.	
Ostergren, O. P., work cited	13
Oxidizing agents, liquid-oxygen explosives	16
Oxygen, excess or deficiency of, effect on temperature of explosion, curves showing	57
first liquefaction of	5
pure, production of, history of	7
See also Liquid oxygen.	
Oxygen content, cartridges at different intervals	28–30
P.	
Paper. *See* Blotting paper; Bond; Kraft; Manila; Newsprint.	
Paper-towel cartridges. *See* Cartridges, standard.	
Paper toweling, as wrapper, tests of	24
Paraffin, as absorbent	4, 17
complete combustion, oxygen for, amount of	28
deflection of ballistic pendulum by	36, 37
senstiveness of	44
use recommended	50
Paraffin cartridges, hardened, tests with, results of	62
Paraffin mixtures, absorption and evaporation rates for	22, 26
complete combustion of, time for	23
composition of	23
specific gravity of	23
Pasteboard. *See* Corrugated pasteboard.	
Paul, J. W., work of	iii
Permissible explosive, length and duration of flames of	51
Pictet, Raoul, liquefaction of oxygen by	5
Pittsburgh, Pa., quarry at, block-hole and bench shots in, views during	68
description of	66
field tests at	66–68
Pittsburgh coal dust, complete combustion of, oxygen for, amount of	28
Pittsburgh Terminal R. R. & Coal Co. *See* Large, Pa.	
Plants, portable, use of	3
Pressure, effect on content of cartridges of	62
Q.	
Quarries, use of liquid oxygen in	2
See also Hillsville, Pa.; Pittsburgh, Pa.	
R.	
Residuum oil, complete combustion of, oxygen for, amount of	28
deflection of ballistic pendulum by	36
sensitiveness of	44
use recommended	50
Rice, G. S., on advantages and disadvantages of liquid-oxygen explosives	1–2
on possible uses of liquid-oxygen explosives	2
on use of wood pulp in French mines	51
work cited	1, 3, 15, 24
work of	iii
S.	
Safety fuse, detonation tests of, results of	47
Salt mines, use of liquid oxygen in	2
Salts, reduction of flame temperature with	4, 56, 59
Sawdust cartridges, strength compared with wood pulp	60
Sherrick, J. L., work of	iii
Short-firing circuits, description of	3
Sieder, L., work cited	8
Silox, as insulator for container	15
Silvered glass containers, use of	13
Simons container, view of	15
Sodium carbonate. *See* Salts.	
Sodium chloride mixtures, complete combustion of, time for	23
composition of	23
specific gravity of	23
Specific gravity, liquid-oxygen explosive mixtures	23
Standard cartridges. *See* Cartridges, standard.	

Generated on 2024-09-29 23:26 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Page.

Starch, deflection of ballistic pendulum by ---------- 36, 37
insensitiveness of ---------- 44, 46, 49
Sulphur, complete combustion of, oxygen for, amount of -- 28
deflection of ballistic pendulum by ---------- 36

T.

Tellier, Charles, work cited ---------- 5
Temperature, effect on explosives -- 79
See also Flame temperature.
Temperature calculations ---------- 53–57
Temperature of explosion, effect of oxygen excess or deficiency on, curves showing ---------- 57
Thermochemical calculation, flame temperatures ---------- 54, 55
Toweling. *See* Paper toweling.
Trauzl lead block, bore hole in, view of ---------- 20
Trauzl lead-block tests, conditions of ---------- 33
results of, discussion of ---------- 4, 35
table of ---------- 34

U.

Unconfined cartridges. *See* Cartridges.

V.

Vaseline, complete combustion of, oxygen for, amount of -- 28
deflection of ballistic pendulum by ---------- 36
sensitiveness of ---------- 44
use recommended ---------- 50

W.

Page.

Water, detonation tests under ---------- 59
See Moisture.
West Winfield, Pa., quarry at, field tests at ---------- 73
Willow charcoal, absorption and evaporation rates of ---- 19, 22
Wöhler, Lothar, work cited ---------- 79
Wood pulp, absorption and evaporation rates of ---------- 19, 22, 26
as combustible ---------- 4, 17
complete combustion of, oxygen for, amount of ---------- 28
deflection of ballistic pendulum by ---------- 36, 37
effect of pressure on absorption by ---------- 62
evaporation curves ---------- 29–30
in cartridges, advantages and disadvantages of ---- 44, 46, 49
use in French mines ---------- 51
use recommended ---------- 50
Wood-pulp cartridge, composition of 19
effect of moisture of ---------- 60
strength compared with sawdust ---------- 60
Wood-pulp mixtures, complete combustion of, time for ---- 23
composition of ---------- 23
specific gravity of ---------- 23
Wrappers, comparison of ------ 24–25, 61
use of ---------- 18, 19

Generated on 2024-09-29 23:32 GMT / https://hdl.handle.net/2027/uiug.30112111813579
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN